The effect of physical properties of sand on the performance of sand mesh turf tracks in Hong Kong

LAW Shun-ying, Shirley

A Thesis Submitted in Partial Fulfilment

of the Requirements for the Degree of

Master of Philosophy

in

Geography

摘要

沙粒結構特質如何影響香港沙網草地跑道的表現

此報告主要研究沙粒的結構特質如何影響香港兩條沙網跑道 (沙田及快活谷馬場)的表現。跑道的結構特質，如水份放射，疏水速度及草本植物重量，都經過詳細研究並探討跑道結構老化，建造設計及陽光照射率與各特質及跑道表現的關系。

建立跑道表現示標，如競賽時間，表面扭力，硬度及草地損耗，有助預測及觀察跑道表現。觀察沙粒的結構特質及表現示標的關系可選出影响跑道的主要原素。

研究所得出的結論有助建立跑道表現目標，管理草地生長，選定改善跑道結構的材料及設計，及管理跑道使用率。爲加强了解影响跑道表現的各種原素，可持續研究量度跑道表面扭力的更佳方法，沙網跑道的壽命及重建跑道常遇到的困難。

ABSTRACT

"The effect of physical properties of sand on the performance of sand mesh turf tracks in Hong Kong"

Thesis submitted by LAW, Shun-Ying Shirley
For the degree of Master of Philosophy
At the Chinese University of Hong Kong in June, 2003

The present study investigated the effects of sand physical properties on the performance of the two sand mesh turf tracks in Hong Kong, the Shatin Turf Track and Happy Valley Turf Track. Tracks physical properties of moisture release characteristics, saturated and unsaturated hydraulic conductivities, oxygen diffusion rates and grass biomass were studied and compared against the influence of profile aging, variations in profile design and different amount of sunlight received by turfgrass.

Tracks performance indicators such as race times, surface shear strength, surface hardness and divot damage were developed to predict and monitor track performance. Correlations between sand physical properties and performance indicators were studied to extract properties for each track that dominates

performance.

The implications of this study on the structuring of the target levels of performance indicators; turf management and cultural practice; determination of construction material and design; and the management of user intensity were also looked at. Further studies on better measurement of shear strength, the maximum life of a sand mesh profile and problems with newly constructed profile were suggested.

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to my supervisor Dr. Chau Kwai-cheong, for his advice and guidance, and most of all for his patience.

The kind approval from the Hong Kong Jockey Club, the Tracks Department in particular, for sampling and studying in the Shatin Racecourse and Happy Valley Racecourse is hereby acknowledged. I would like to extend my gratitude to Mr. John P. Ridley and Mr. Pako P.C. Ip for their continual support and encouragement.

Special thanks must be given to Dr. Tony O. R. Field and Mr. Jim Murphy for their insights and technical guidance, without which this study would not have started.

LIST OF TABLES

LIST OF FIGURES

TABLE OF CONTENTS

CHAPTER 5 THE STUDY OF PERFORMANCE INDICATORS AND PROFILE PHYSICAL PROPERTIES

CHAPTER 1

INTRODUCTION

1.1 The Hong Kong Jockey Club

The Hong Kong Jockey Club (HKJC) is a non-profit organization that provides the only legal channel to conducting and betting of horse racing in Hong Kong. The HKJC has two racecourses; the Happy Valley Racecourse has one turf track is situated in Wan Chai District Hong Kong Island, which is one of the few racetracks located in the city centre. The Happy Valley Racecourse was where racing has originally started in Hong Kong. The second racecourse is the Shatin Racecourse in located in Shatin, New Territories, which was built on reclaimed land in1978. It has one turf track for racing, and one turf gallop strip for training. It also has two All Weather Track for racing and training.

All racetracks in HKJC are managed and maintained by Tracks Department. The Happy Valley turf track is roughly 5.4 hectares in area and the Shatin turf track is about 10 hectares. The turf track surface is made up of two grass species:

- Tifton-419 is a hybrid bermuda grass (*Cynodon dactylon x C. transvaalensis*) which is a perennial warm-season turf grass. This grass type is widely used in racetracks, golf clubs and sports fields.

- Perennial ryegrass (*Lolium perenne*) is a cool-season turf grass that supports racing from mid-October to early May.

1.2 History of Sand Mesh System in Hong Kong

The current turf tracks of the Hong Kong Jockey Club are built on reinforced sand based profile, which is quartz sand with plastic mesh element. Prior to 1986 the two turf tracks are still soil based. During the 1982-83 racing season, more than 70 number of turf races were cancelled owing to heavy rain. Under heavy rain, the saturated soil will turn soft and become too heavy to race. To target the torrential rainfall, from 1986, the Jockey Club began to experiment different mixes and types of reinforced pure sand profile at the Shatin Racecourse 1000m Chute. Eventually the Netlon sand mesh system was chosen.

The Shatin Racecourse, which was built in 1978 and converted to a sand mesh system in 1988, was among the pioneers of sand mesh racetracks. Happy Valley was also converted from a soil track to sand mesh track in 1989 with another redevelopment project in 1994/95 to improve track configurations. Such large-scale redevelopment programmes are very time consuming and have very significant impact for racing arrangements and betting turnovers. Hence, such projects are only done sparingly and as last options.

1.3 Problems Encountered in Track Maintenance

In the 1980s, the main objective was to explore turf profiles that can handle intense rainfall and racing. Therefore drainage rates for racing under downpours were the sole concern. The original sand mesh profile in Shatin, which was 350 mm deep of medium coarse sand (200 mm of sand mesh on top of 150 mm of pure sand) overlaying a section of coarse gravel was then designed by the Club's engineers based on studies done by Netlon and tests results at Shatin. As the popularity of racing in Hong Kong increases and the number of horses per stable increases, the number of race meetings per season increases from 50 racedays in the 1980s to 78 racedays in the season September 2002 to June 2003. In addition the number of races per day has also evolved from 8 races to 10 or even 11 races on weekends, and 6 races to 8 races on Wednesdays. More racing and more horse training has created exponential increase on track usage. Tracks' management concern has changed from mere drainage rates to the ability to cope with such amount of usage under all types of weather and racing conditions. As an international first class race club, the tracks need to provide a platform that is stable, consistent, safe and aesthetically pleasant for world-class racing.

During the past ten years, the Jockey Club has encountered several incidents that had raised new concerns on track performance. After the redevelopment project of Happy Valley in 1994-95, when the track re-opened in November 1995, it was very sandy to race on. Flying dust and sandy kickbacks were evident during races. Apart from creating a lot of repair works for tracks management, these sandy kickbacks have impaired the best performance of jockeys and have caused an increase in eye injury among horses. This phenomenon is quite characteristic of immature sand mesh profile where the profile surface was unable to retain sufficient moisture to provide an acceptable level of stability. In new profiles, macropores are abundant to give fast drainage rates which could be excessive. In addition, the organic matter content is also low, thus unable to retain moisture at the top. The combined effect of fast drainage and low moisture retention will produce a track that is always too dry to race on. As it takes time for the track to mature to an optimum level, the short term solution was to roll and compact the track before and during races to increase bulk density of profile and improve surface stability. Therefore the management technique of a new profile is very different from mature tracks.

On March 13 1999, several turf races in Shatin racecourse was cancelled due to skidding problems. On that particular occasion, the turf track was performing well at the beginning of races, and then light rain started. As the rain was very light, it was not enough to wet through the profile and most of it sat on the leaf surface creating a thin film of water on turf surface. To provide a fast and easy to repair racing surface, the track was usually maintained at 'good to firm'[1] condition, which is quite hard and has minimal divots. As a result, horses were unable to penetrate such a hard surface. Without proper traction, horses skidded on the hard and wet surface. It was unsafe for jockeys to ride in such condition, thus turf races were forced to cancel. From then on, new grounds for surface hardness were developed and more awareness was raised on track going. Apart from providing a track for horses and jockeys to ride at their best, it is equally important to ensure that it is safe with adequate hardness and traction. Grasses should be thick enough to be green and hold the profile together but not excessive to be slippery.

The last race on May 22, 2002 in Happy Valley was also cancelled due to unexpected thunderstorm. An old section of Happy Valley, which was not reconstructed in the 1995 redevelopment project, had failed to drain under the sudden high intensity rainfall. Although the section was a sand mesh profile, it was still unable to cope with it. The track surface became waterlogged which made the towing of the starting gates very difficult and jockeys were unwilling to ride under such condition as unstable grounds could again cause skidding and potentially be very dangerous. This has triggered alarms to the degree of deterioration in sand mesh profile and the maximum lifetime of such systems. Years of racing and grass growth has caused significant modification on the physical properties of the profile, such as the accumulation of organic matter as grass plants die off and the collapse of drainage pores due to usage and vehicle

[1] "Good to Firm" is a description of the most common condition of track hardness where the penetrometer reading is 2.50-2.75 and horses will race slightly faster than standard times.

traffic. It became essential to study the degree and speed of aging of sand mesh system for timely reconstruction of profile. The cancellation of races not only induce huge losses in betting turnover, they have also created negative comments on both local and international critics, which would jeopardize the Club's reputation.

Besides, the Shatin Racecourse was built on reclaimed land; over the years sections of the track have different degrees of settlement. To correct the surface level, settled areas need to be rebuilt. However, due to the short working window in the non-racing season, only a small portion of the track can be rebuilt each year. As the years of reconstruction works proceed, sections of the track ended up in various degrees of aging and have a variety of physical properties. In order to produce a uniform track, different maintenance strategies need to be adopted to balance the effect of ages. It is therefore essential to have a better understanding on the relationship between profile aging and physical properties.

The climate of Hong Kong has a distinct summer and winter; this makes it necessary to have a warm-season grass and winter-season grass to cope with these growing conditions. The summer grass used in HKJC is a hybrid bermuda grass, Tifton-419, which enters dormancy from November and resumes active growth in mid-May depending on temperature and amount of sunlight. As the racing season stretches from September to late June, in 7 out of

10 months, we depend heavily on the winter grass, perennial rye grass. The transition in April and May when we gradually convert from a rye grass track to a Tifton track is most critical. If conditions are unfavourable, rye grass could be wiped out too early before Tifton regeneration is triggered. Under such circumstances, grass coverage will be significantly reduced. Besides being aesthetically unpleasing, the loss of grass coverage and root systems will have a huge negative impact on surface hardness and stability. The layer of dead plant material overlaying the track surface would also impede water infiltration hence reduce drainage rates. Ponding would occur after raining or irrigation, which could cause skidding problems and promote the growth of algae on track surface. So such conditions could lead to race cancellation, as June 2002 when an entire race meeting in Happy Valley was cancelled and transferred to Shatin due to poor grass coverage and poor stability. Hence, the grass factor will affect the physical properties of the profile and vice versa.

Sand based profile has the advantage of fast drainage and it is theoretically impossible to compact sand. However, sand based track requires more sophisticated management because it depends on the delicate balance of profile moisture for proper functioning and problems on leaching and traction. Over the years of management experience, the general problems encountered are the aging of profile, the lack of surface stability in the initial years of construction, and the extend these factors contribute to the overall track performance. To increase the effectiveness in managing sand based turf track, it is necessary to understand the relationship between the changes in the physical quality of a sand profile and the effect of these changes on the growth of grass plant. Finally, understanding the combined effect of the physical properties and grass quality on the general track performance is essential to racetrack management.

CHAPTER 2

CONCEPTUAL FRAMEWORK OF STUDY

2.1 Sand and Sand Mesh Systems

In the 1960s, the increased play intensity in golf clubs started the movement from natural soil based green to sand based green. Subsequently, there was the trend to build sand based turf sports field and racetracks, which is originally soil based as well. In a soil based profile, as play intensity increases surface compaction intensify and soil structure begins to deteriorate. As profile pore space decreases, bulk density increases, the soil becomes slow to drain, hard in the surface and low in oxygen. Waterlogged and anaerobic profile makes turf growth, especially root growth, very difficult. Soil based profiles simply could not handle the increase in play intensity.

To achieve healthy grass growth, a minimum air porosity of 15% was suggested by Radko (1974), and compacted soil could seldom reach this porosity level. In addition, the disruption of macropore from compaction means that drainage rates are greatly reduced, rendering the surface incapable of draining rain or storm water effectively. Surface becomes waterlogged or too soft to play and usage is disrupted. To overcome these problems, sand that has a faster drainage rate and is much less prone to compaction is used to build golf greens, sports fields as well as racecourses.

Beard and Sifers (1989) started to study the incorporation of randomly oriented mesh element in turf root zones. In these reinforced rootzone systems, the stress transfer mechanism between and among soil particles and the mesh elements relies on the interlocking dimension of mesh and roots. Similar enhanced system had also proven to be effective in stabilization of civil engineering earthworks. Studies were then initiated to study the feasibility of using mesh element-sand matrices in turf rootzones, especially in sports fields, in order to reduce divoting and tear of turf, enhance soil-turf stability and increase surface traction. Mesh elements are discrete 50 mm x 100 mm rectangular nets with open ribs extending from the perimeter, as manufactured by the Netlon Company from polypropylene. The square aperture between individual ribs of the extended mesh was 10 mm.

The study by Beard and Sifers (1989) had shown that the inclusion of mesh had significantly reduced the size of divots, both in terms of length and width. This has then reduced surface recovery time by 50% which meant there is a potential to double the use intensity of mesh reinforced surfaces. With the potential benefits in mind, the Jockey Club was among the pioneers to install this type of sand mesh system on racetracks, first at the Shatin Racecourse, then at Happy Valley[2]. Since then reinforced sand profiles has been widely used in sports fields as well as racecourses worldwide.

---

[2] Sand/Mesh turf track system is also used in the Royal Randwick Racecourse (Sydney, Australia), Mooney Valley Racecourse (Victoria, Australia) and Kranji Racetrack (Singapore)

2.2 The Basic Components of a Turf Track System

To properly manage a turf racetrack meant to fulfill the requirement of a galloping horse, the basic needs to maintain a healthy grass cover and to sustain the tight racing fixture. As stated in the Awapuni (New Zealand) Report by Field (1997):

> A racetrack is rated with respect of the ability of the track to provide a root medium capable of supporting vigorous turf growth and a track that performs to a high standard under racing throughout the season. Vigorous grass growth provides aesthetic appeal to the race track, a hard wearing and durable turf with good recovery, and gives strong root growth minimizing the cutting out of the track under racing in slight damp soil condition.

To be successful it is necessary to consider the track as a dynamic living form, which is a system of grass plants, thatch[3], sand, water and air, while horses are considered to be the end users. Climatic conditions and cultural practices, as external factors, have significant influences on the state of the track surface, which then cause variations in horse performance (Figure 2.1). Canaway and Baker (1993) suggested a dynamic flow chart to reflect playability, which is a very useful concept in understanding the components influencing track performance. As the tracks management team, the aim is to control these variations within a measurable limit and maintain the tracks' physical, mechanical and aesthetic qualities. However, these management objectives often result in conflicting interests between the mechanical quality of surface for horses and a reasonable condition for turf growth.

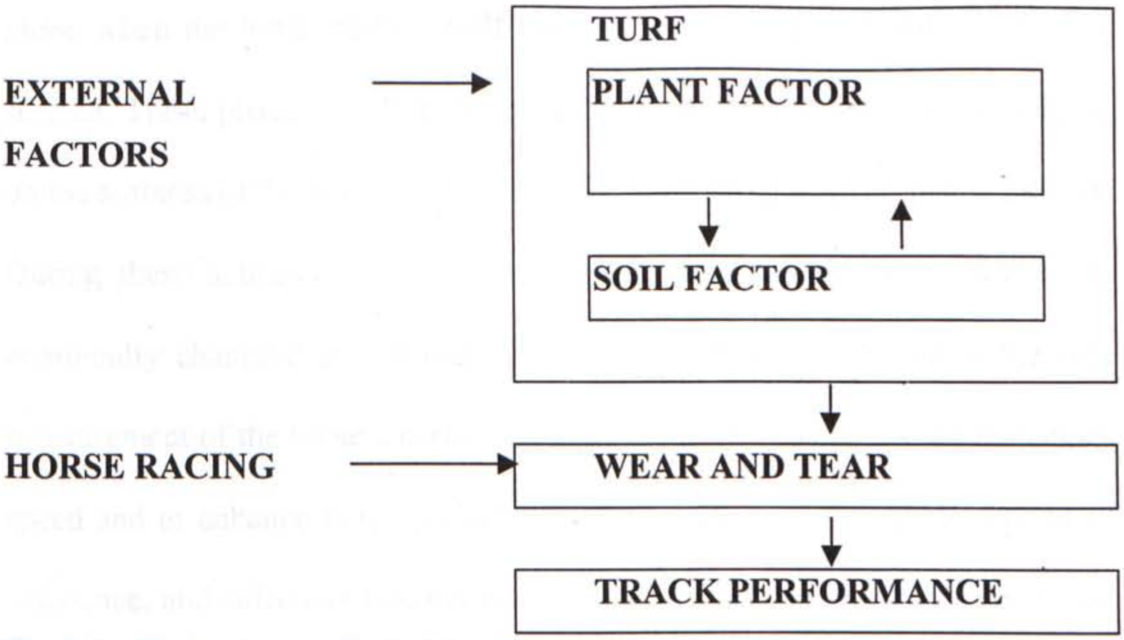


Fig 2.1 - The concept of track performance

As mentioned by Catrice (1993), during a race, a horse places all its weight (over 1000 pounds) on one single leg at a time, which translates to a considerable amount of energy concentrated on a small surface area.

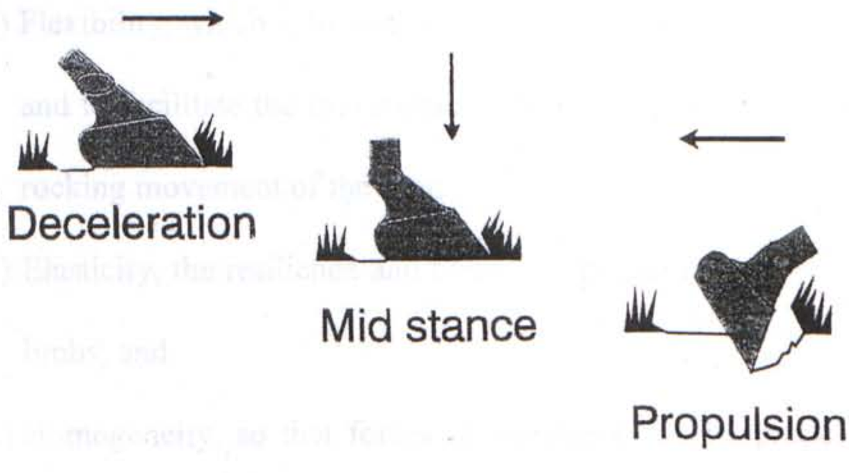


Fig 2.2 – Stance phase of the horse limb cycle

[3] Thatch is partially decomposed coarse organic matter.

At the time of impact, the moment when the horse hoof hits the turf surface, a sharp deceleration is produced, and shock is absorbed by the horse's muscular contraction and by the track surface. It is followed by the propulsion phase when the horse pushes itself forward with a turning action on the turf surface. These phases result in the track being marked or damaged depending on the softness of the track and the strength of the surface cover, that is the turf. During these actions, the horse's legs exert forces on the track, which are continually changing in intensity and direction. In a race, speed is the sole measurement of the horse's performance on the track. To achieve a satisfactory speed and to enhance horse performance, it is important to provide a point of resistance, and sufficient traction near the top of track surface to accelerate the horse.

To successfully enhance a horse's speed, Catrice (1993) suggested several qualities of the track:

(1) Flexibility, which is to soften the impact in conjunction with the horseshoes, and to facilitate the movements of the joints and their co-ordination in the rocking movement of the foot;

(2) Elasticity, the resilience and bounce to propel the horse without damage to limbs; and

(3) Homogeneity, so that forces of resistance can be produced in a constant way and supply a standard point of resistance over the whole of the course.

In order to provide a sustainable surface, a compromise must be found between mechanical qualities of flexibility and resilience of the track. These translate ultimately to three very influential track characteristics – track hardness, surface stability, and uniformity.

2.3 Track Characteristics

2.3.1 Hardness

Track hardness, also refer to as track going, is a measure of vertical penetration resistance. This factor has significant influence in race times, action and reaction forces on horses legs and drainage to turf surface. On firm tracks, a minimal amount of impact force is absorbed by the track or wasted in deforming the surface. Most forces is used to propel the horse in a forward motion, hence, faster race times are achieved. However, this puts a lot of pressure on horse legs as the tendons absorb most of the reaction forces. Fatigue and injury could occur if horses frequently race on a firm track. Therefore, the well being of horses are jeopardized and firm tracks are usually not welcomed by horse trainers and onwers. On the other hand, divoting and damage to the turf surface is less severe, thus gives the track a better chance to sustain approximately 35 race days per season. On the contrary, soft tracks will give slower race times and more damage to the turf surface. With an average of 9 races per week, recovery period is limited and constant soft going will be detrimental to the condition of the turf. A fine balance between going and divoting must be drawn to produce fast race times and minimize divot yet to provide enough traction for galloping. Track hardness is measured on site using either a penetrometer or a clegg hammer which measures the mechanical penetration resistance and impact deceleration respectively.

In sand profile, hardness is greatly influenced by the moisture content. Strength and cohesiveness of sand increase with moisture content as it is being wetted up from dry to moist. However, when moisture exceeds the plastic limit, resistance will decrease sharply and sand becomes flowable. At very high moisture content, sand profile will become soft and easy to penetrate. Moisture retention, the ability to hold on to water, is governed by the physical properties such as particle size distribution, porosity and profile depth. Particle size distribution has major influence on capillary forces and drainage rates. Finer sands have higher capillary retention, which will result in higher moisture content even after drainage ceases. In general if both profiles are at field capacity, a fine sand profile will equilibrate at a higher moisture content than a coarse profile. Hence, coarse profile is prone to over drying and fine profile for over wetting.

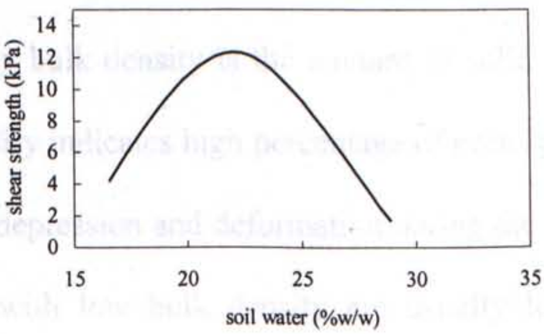


Fig 2.3 – Profile Moisture Content VS Shear Strength

Sand profiles in the racecourse are built with a perched water table, that layer of relatively fine sand overlaying a layer of coarse gravel. The abrupt change of particle size at the interface prohibits water from draining freely from the sand to the gravel layer. Only when the top sand layer is saturated will gravity pull water from the top. This profile ensures that enough water is stored in the top profile to support plant growth while efficiently draining excess water. However, to ensure that the perched water table works as desired, the depth of sand must match the particle size density in order to reach a desirable surface moisture level. If the sand is fine and profile is too shallow, drainage rate will be too slow, the surface will always be saturated. This will result in slow going, excessive divots, and most important, high surface moisture would discourage deep rooting and healthy grass growth. On the contrary, if sand is too coarse with a deep profile, the surface will be depleted with moisture. Surface will be dry which will produce a firmer track but as the track continues to dry, surface will become dusty and unstable. Hence, the depth of sand profile must be designed to match the specific sand used for construction to provide desirable surface hardness and stability.

Dry bulk density is the amount of solid mass per volume of soil. Low bulk density indicates high percentage of pore space and voids, which provides space of depression and deformation during the impact of a horse hoof. Hence, sections with low bulk density are usually loose and soft in dry weather. However, in wet weather, these areas with more pore space are faster to drain and will resume normal track condition sooner. In high bulk density areas, pore space is limited, and more time is required to drain from a waterlogged track to field capacity. The track will remain in a softer condition for a longer time.

Apart from these physical properties, the amount of organic matter also plays an important role. It can act as a natural sponge to absorb and store water. McCoy (1992) suggested that higher organic matter content contribute to more water being stored in the profile at field capacity that results in a softer track. However, during extremely dry weather, organic matter will dry up and become hydrophobic. In this situation, sections with high organic matter will become difficult to wet, the option to soften the track with irrigation will not be functional. In addition, organic matter has a lower bulk density than sand, hence softer to gallop on. Therefore, an increase in organic would give a softer going in moist to wet weather.

2.3.2 Stability

Stability is a measure of surface resilience to the propulsion action of horses, mainly accounted by the shear or torque strength. Gibbs et al (1989) studied the stability of a medium-fine sand root zone using measurements of traction, penetration resistance and their relationship with bulk density, water content, plant total mass and root organic matter, and ground cover. The results showed that most of the variance in surface stability could be accounted for by changes in root organic matter, that is root mass. A positive relationship between root mass and traction was observed. It was also found that the loss of grass cover and root mass has severe consequences on pure sand systems, where extensive erosion hollows can develop. This situation is particularly severe if the surface is allowed to dry out and is not rolled to restore stability. In erosion hollows, the sand is loose and easily kicked out and this has major effects on traction and hardness. There is a general tendency to assume a positive correlation between the stability characteristics of a natural turf and the percentage of live ground cover or the amount of top growth biomass. However, the relationship between surface traction and ground cover could only be supported initially. The increase in aboveground growth itself contributes to only a negligible improvement in surface traction. Thus, the emphasis is to be put on root material in the study of stability.

Interestingly, a negative relationship was observed in Gibbs' studies (1989) between bulk density and traction as oppose to the general findings of other studies. Conventionally, it is expected that an increase in bulk density would lead to increased strength. It was suspected that above an optimum bulk density, root penetration might be hindered, as a significant force will be required from the root tips to push through the soil particles. As the degree of compaction increases, a decrease in pore space leads to a decrease in oxygen diffusion rates and an increase in available moisture. This combination of physical properties would be an adverse environment for extensive root growth and would eventually lead to a decrease in total root mass. It was suggested that if the importance of root mass were significantly higher than bulk density, then this phenomenon of negative relationship between bulk density and traction would be observed. However, this theory has not been widely tested yet.

A positive correlation was also observed between organic matter content and traction. In a pure sand system, organic matter could act as a storage medium for moisture and nutrient. It could also be viewed as a natural soil coagulant to bind sand particles together. One of the major set backs of a pure sand profile is the fast drainage rate which could lead to excessive loss of surface moisture and severe leaching of nutrients. The presence of organic matter could alleviate the intensity of these negative impacts and promote better turf growth that would result in better surface coverage and higher root mass.

Gibbs' (1989) study suggested that an acceptable level of traction could be achieved even without the presence of roots and ground cover. Moisture content, in this case, was shown primarily to determine the traction characteristics of sand. However, to achieve sustainable traction in this situation is difficult because of the lack of cohesion of sand, unless the surface is being rolled regularly after irrigation to compact the sand.

2.4 Problems Encountered in Sand Mesh Systems

In reflection to the basic qualities of a racetrack, several maintenance problems have been observed over the years which have major impact on track performance.

2.4.1 Maturity of sand mesh system

Sand based turf systems are designed to meet physical requirements for playablility. Turf plants in this system gradually modify these physical characteristics. However, specifications for constructions are determined using a pure sand system, the influence of plant growth is usually not incorporated during the construction phase. Studies done by Murphy and Nelson (1979) showed a tenfold reduction in percolation and changes in pore size distribution with turf that is only 6 months old. It is also not uncommon in sports turf to discover a reduction in plant roots both in amount and depth, in sand culture with time. Baker (1990) considered air-filled porosity as a good indicator of physical condition of growth media. Radko (1974) suggested the minimum limit for air filled porosity in sand profile of 15% while Bingaman and Kohnke (1970) determined the level of 10% to be the minimum acceptable level for any turf medium, soil or sand based. These minimum aeration level were set to determine the minimum requirements for turf to provide sufficient soil oxygen for rooting, enough macropores and pore continuity for drainage. Murphy et al (1993) suggested the deterioration in sand media arose from the occlusion of macropores with organic matter. As profile ages, organic matter content increases resulting from the gradual build up of root fragments and organic breakdown products. Organic matter accumulating in the sand root zone would lead to decrease in macroporosity, increase in water holding capacity and the proportion of surface pores filled with water (McCoy 1992).

In an aged profile, increased surface water would create a softer than average going, which would slow down race time and increase divoting. Surface water would also discourage deep rooting and have negative impact on plant growth due to decreased oxygen availability. Decreased marcoporosity could significantly decrease percolation rates and therefore affect the track's ability to handle storm water. Aged sections of the track are prone for surface ponding and are easily compacted by wet weather traffic.

Although sand based profile has been widely used in golf and sports field, its aging characteristic is still unfamiliar, especially in the subtropical region. Most aging studies and specifications for minimum porosity levels were done on golf greens and in the temperate regions, thus, their applicability on local racetracks is still to be confirmed. Separate sections of the Shatin grass track were reconstructed at different years to correct for settlement problems. Therefore, these sections are all of different ages. The variations in maturity have lead to differences in drainage properties, track hardness and grass growth, in terms of growth rates and species composition. These variations would in turn lead to variations in performance. To tackle the aging problem, it is necessary to understand how age changes different physical properties and track performances.

2.4.2 Surface instability in the early years after construction

Surface stability is the measure of the track's resilience to propulsion of horses without damaging the turf surface. Newly constructed areas, especially the Happy Valley track after the 1995 reconstruction, are characterized by excessive dust and sand kick back during racing, which results in high divoting percent. The combination of poor turf cover and unsatisfactory recovery will increase susceptibility to damage in the following race meeting. The track will always have to catch up with the tight racing fixture. This would affect the flexibility in planning race programmes and reduce the possibility to increase the number of races and hence increase revenue.

The initial designed depth of the track profile was 350 mm for both racecourses. This depth was determined without the consideration of the moisture retention characteristics of the sand used for construction. The sand used lays on the coarser side of the sand particle size distribution for construction of sand based golf green in the specification of the United States Golf Association (USGA[4]) and the Sports Turf Research Institute (STRI[5]) standard. From previous laboratory results, at soil water tension of 350 mm the surface moisture content will only be at 12-15% which is not enough to sustain

[4] USGA is the national governing body of golf in the United States.
[5] STRI is a sports and amenity turfgrass research and consultancy centre in the United Kingdom.

the shear action of racing. The combination of coarse sand and deep profile leads to low surface moisture. Water stored at the designed perched water table is too deep to replenish the dried up profile surface in time. Track surface will become too dry, particle cohesiveness will decrease and surface sand will become too loose. Excessive surface dryness decreases soil strength, and sand surface will be easily deformed on racing, which gives rise to dust and kick back.

This phenomenon is most prominent in newly constructed sections where organic matter content is low. Organic matter could function as natural water storage and could also act as a soil coagulant. Organic matter content could therefore increase both moisture level and cohesiveness, subsequently alleviate the negative impact of a deep coarse sand profile. However, the accumulation of organic matter is a slow process, and such time frame might not be feasible in short- to medium-term management.

To amplify the problem further, bulk density in new profile is usually low due to lack of compaction. By design, fresh grounds have high macro- and micro-porosity, with little organic matter and accumulative effect of traffic. Most of these pores are not collapsed and should remain functional. These meant that drainage rates are fast. Bulk density, although is only loosely correlated with soil strength, account for some variance in soil shear strength (Gibbs and Baker 1989). Low bulk density translates to less surface strength, therefore more vulnerable to divoting. Fast drainage rates further worsen the situation; irrigation water will be immediately drained from the surface profile and lost to the inaccessible perched water table or drained away through the gravel layer. High porosity and void content in the initial stage results in poor water holding capacity which further exaggerates surface dryness.

To overcome this problem, previous overseas consultants worked on the racecourses had proposed to either rebuild the entire profile to meet the correct designed depth or to wait until the track slowly matures to the desirable organic matter level. As rebuilding the entire race track is time consuming and very costly, both in terms of construction costs and the impact on betting turnover, this option is not viable. Hence in 1998, two sections of the Happy Valley turf track, section immediately after the winning post and at the back straight right after the Stable bend, were rebuilt using a new Strathayr design as an experiment. These new sections use the same quartz sand as in other parts of the track but a shallower profile depth was obtained to meet the water retention characteristics of this sand. These trial sections were meant to reduce the problem of surface instability by using a shallower profile depth to correct surface dryness. But the performance of these sections are still to be evaluated.

2.4.3 Shading of sections of the Happy Valley track

One of the greatest attractions of racing in Happy Valley is the close proximity between the grandstand and the turf track. It is also because the grandstand is so close to the track that the Home Straight (from 300m distance marker to 100m after the winning post) is totally shaded in the afternoon. Therefore, only half the track could receive full sunlight during the day hours. Previous experiences with the track and comments from the track supervisor have suggested that grass growth was inferior in the shaded section of the track. The limited light hours meant that the hours of active photosynthesis could be lowered, surface water also stays on the track surface for a longer period and the section is also more susceptible to disease infestation.

Growth rates, in terms of lateral growth and total root mass, were lower in these areas. The amount of divoting is often excessive as higher retained moisture leads to softer going and reduced roots and stolons give rise to substandard surface strength. Problem arises as low growth rates and high divoting results in low recovery rates. Turf cover in the area is affected even after weeks of recovery period. Unsatisfactory turf cover would further decrease surface strength, as the major binding agent of the sand is removed, surface stability is then in stake.

In addition, the climate of Hong Kong makes it necessary to have a winter grass (perennial rye grass) and a summer grass (Tifton 419). April and May is the critical transition period when the winter grass starts to die off and the summer grass resumes active growth. The growth rate of summer grass is greatly determined by soil temperature and the amount of bright sunshine hours.

Along the Happy Valley shaded home straight section, lower temperature and sunlight has led to a much slower Tifton regeneration. As the rye grass dies off rapidly under high air temperature and humidity, slower regeneration along the home straight leads to a temporary poor grass coverage which affects surface hardness, stability, drainage and ultimately track performance.

2.5 Objectives of Study

The objectives of this project are five-fold:

1. To quantify the relationship between the physical factors of sand with turf grass growth and racetrack performance.
2. To identify measurable qualities that can improve the quality of racetracks and ultimately simulate an ideal track.
3. To investigate the temporal changes of a turf track – changes over a race season and the aging process.
4. To explore the possible solutions to overcome problems encountered in newly constructed profiles.
5. To evaluate the effect of external factors on sand and track performance.

2.6 Hypothesis of Study

In light of the above problems three hypotheses regarding track performance were developed:

1. Age changes the physical properties of the sand profile and determines track performance

2. The designed depth of profile, whether designed depth match the characteristics of the sand, dominates performance
3. The amount of sunlight received by the track determines the performance of the grass and hence dominates track performance

The criteria for study will be divided into three sections:

1. Physical properties of sand, which will include particle size distribution, water release characteristics, bulk density, organic matter content, saturated and unsaturated hydraulic conductivity and oxygen diffusion rate.
2. The grass factor will include botanical composition, biomass – top growth, stem and root mass.
3. Performance indicators used are shear strength, vertical penetration resistance, surface hardness, and percent divoting.

2.7 Significance of Study

This project will be the pioneers in monitoring performance and changes in sand physical properties, as most previous studies have been done on golf greens and sports fields. Results will be very useful in developing day-to-day as well as non-racing season profile renovation works. It would also fill in the knowledge gap between the management of a sports field and a racetrack.

CHAPTER 3

LITERATURE REVIEW

3.1 Components of a Turf Track

Turf tracks are a living form in a state of constant change and made up of:

1. Soil with physical or mineral matter, chemical, microbiological composition
2. Plants composed of stems, leaves, roots
3. An intermediate layer made up of roots, detritus and decomposing organic matter called thatch
4. Water and air

The influence of climatic conditions should cause the state of these surfaces to vary in such a way that the horses can demonstrate their ability and muscular and skeletal solidity which are necessary for breeding. But variations in the state of these surfaces must be controlled within certain measurable limits while at the same time maintaining their physical, mechanical and aesthetic qualities.

High skill is necessary to match the needs of the growth of a system of perennial plants and to the mechanical qualities of a surface used for sport while taking into account the best possible appearance. These contradictory and unconnected needs result in constraints, which are often conflicting for both horses and turf.

When considering the needs of thoroughbreds, during a race, a horse places all its weight on leg at a time, which represents considerable energy given the mass and speed. For optimum performance, it is important that the horse should find on the track a point of resistance near top of the surface. According to Catrice (1993), an ideal racing surface should comprise of flexibility and elasticity. To attain these qualities, a compromise must be found between the mechanical qualities of flexibility and resilience of the track.

Horseracing and turf track maintenance are often full of conflicting requirements:

1. The racing calendar – the needs of the horses are at odds with the aims of turf maintenance operations and so conflicts follows when pressure as such that has a detrimental effect on the turf. If racing calendar is drawn up without taking into account the different growth phase of the grass, and if overuse of the track prevents the carrying out of planned maintenance and repair operations, the quality of turf will be at stake.
2. Irrigation – the matching of growth of the turf to track flexibility and elasticity is a result of maintaining optimal soil moisture for good cohesion. The determination of water requirements is the result of balance between what is needed to feed the turf, and maintaining watering just enough to provide the degree of track flexibility required. What is considered sufficient for the turf is often considered to be excessive for the needs of the

horses, which became a permanent conflict between turf management and racing.

3.2 Age Development in Sand Based Turf

Sand-based turf constructions are designed to meet physical requirements for plant growth and drainage requirements for playability. Turf plants gradually modify these physical characteristics. Three stages of maturation was defined by Field et al (1993) based on changes in water to air relationships in the profile media. The stages vary in length according to sand grade. Initially, design requirements are met better by medium than fine sands. During the second stage, sand media increasingly depart from acceptable performance standards. Coarse sands lost macroporosity faster than fine sands but both types retained better aeration than most soil systems. After about twenty years the macroporosity of both sand types was little different than that found in compacted soil media.

In general, turf growth and surface playability of sand-based turf is more than satisfactory over the early years. However, the presence of turf plants quickly modifies the sand environment. Murphy and Nelson (1979) showed a tenfold reduction in percolation rates and changes in pore size distribution with 6-month old turf. In sports turf, plant roots have reduced in depth in sand culture with time. Field et al (1993) had studied pore size distribution and water to air relationships in golf greens of various ages in order to study the dynamics of aging in medium and fine grade sand growing turf. In their study, total porosity, macroporosity, water holding capacity (WHC, water held at less than the gravitational tension determined by the depth of sand) and water filled pores at the surface (WFP, the percentage pores filled with water at that same gravitational tension) were found to change dramatically over age as shown in Table 3.1.

Table 3.1 - The age at which sand profiles reached the critical limits of 15, 10 and 5% macroporosity and their physical properties

	Macroporosity					
	15%		10%		5%	
Soil character	med	fine	med	fine	med	Fine
Age (yrs)	**10**	**5**	**15**	**13**	**19**	**20**
Total porosity %	47	48	50	53	51	57
WHC %	27	31	31	37	35	42
WFPS %	77	68	88	81	97	92
Organic matter %	3.8	2.8	4.8	4.8	5.7	6.7

The 15% macroporosity level, above which design requirements are still met, was reached only 5 years in the fine sands. Even though the rate of loss of macroporosisty was greater in the medium sands, they retained acceptable physical standards for 5 years longer than fine sands. The difference between the sands in water holding capacity became increasingly greater with age, with the fine sands holding more water even with the tension from greater depth of sand.

Gibbs et al (1989) suggested a critical limit for organic matter accumulation at 5% for sand-based turf. Field et al's (1993) results suggested that both fine and medium sand systems have deteriorated to macroporosity standards below that of acceptable soil-based systems by the time this limit is reached. They have therefore recommended a value of 4.5% as a more realistic upper limit for organic matter content in sand medium. The deterioration in the physical characteristics of the sand root zone is assumed to arise from occlusion of macropores with organic matter. Carrow and Wiecko (1989) has also observed that the primary cause for reduction of infiltration rate on well constructed high sand golf greens were roots filling much of the surface pore space. Field et al (1993) suggested rather occlusion appears to results from the gradual build up of root fragments and organic breakdown products. Therefore, turf cultural management of sand systems must aim at maintaining the organic matter in the root zone within the critical limits that still meet design macroporosity.

3.3 Surface Stability of Sand Rootzone

Although a sand profile can provide a high quality surface, if not managed correctly sand rootzones maybe affected by poor surface stability, a property predominantly determined by the presence of turfgrass roots. The retention of an intact grass cover is therefore important because above a certain critical level of use, grass cover could not be sustained and surface instability will become unacceptable. The 1989 studies by Gibbs et al were conducted in a medium-fine sand profile pitch oversown with perennial ryegrass. Stability of the field was studied by making measurements of traction, penetration resistance, bulk density, water content, total and root organic matter, ground cover and usage.

The results showed that most of the variance in surface stability could be accounted for by changes in root organic matter. For every increase in root mass, an increase of nearly 5Nm traction could be expected. There is a general tendency to assume that stability characteristics of natural turf are related to the percentage of live ground cover and/or the amount of plant biomass but not associated with root material. Initial results on the relationship between surface traction and ground cover from Gibbs et al (1989) would support this view. However, further testing have shown that top-growth per se conferred only a negligible improvement in surface traction, thus emphasizing that it is root material and not the above-ground plant material that is important to surface stabilization. They have also stated that a certain degree of stability can be retained when there is no ground cover and without the presence of roots. This raised question as to whether it is absolutely necessary to retain ground cover for a minimal level of stability when these conditions can be achieved without the turf grass. Such a conclusion would suggest that there is no physical limit of use for a sand-base profile, may it be football pitches or racetracks. However, the traction characteristics of sand without roots were dominated by moisture content, indicating that irrigation management would be crucial to maintaining a satisfactory surface for play and racing once ground cover is lost. Nevertheless, the sand profile would still be liable to instability once it had been initially disturbed because of a lack of cohesion of sand in the absence of roots. Thus, irrigation management must be coupled with intensive rolling regularly to avoid problems with low traction and for a sustainable level of stability. However, these practices could lead to other problems of compaction and continual deterioration of topgrowth.

3.4 Physical Properties and Botanical Composition

A survey of 19 New Zealand racetracks was taken by Field and Murphy (1990) to investigate the relative state of the turf and subsurface soil. Botanical profiles of the turf cover were analysed to indicate the acceptability of the racing surface and to determine whether species composition could be used to diagnose subsurface problems. This study is an excellent indication of the interaction between profile physical characteristic and surface grass cover.

The objective of racetrack managers to produce a high quality turf, on which to race thoroughbreds, is infrequently met because marked differences in plant species growing in turf arises under the disparate combinations of racing use and maintenance inputs. Factors such as the frequency and season of racing, fertilizer applications and soil physical treatment can influence the balance of turf species found on racetracks. Results showed that ryegrass, our common cool-season turfgrass, was associated with lower soil relative compaction, while *Poa trivialis* (blue grass, a common grass-type weed) domination indicated greater tolerance of high levels of relative compaction. As compaction increases there is a gradual loss of air-filled porosity to water filled pores at all times, discouraging deeper-rooted grasses such as ryegrass which are highly favoured by tracks managers to provide a track with a higher stability. Their results showed a sharp swing in species composition at around 90% relative compaction, when Poa comes to dominate the turf surface.

Soil relative compaction has important effects on soil physical characteristics that determine the playability of turf surfaces and turfgrass growth. Murphy and Field (1990) derived that the measurements of soil compaction include relative compaction, aeration porosity, oxygen diffusion rate and hydraulic functions. Compaction is defined as a process whereby external forces compress a mass of soil into smaller volume. As compression progresses, profile structure is usually destroyed as air-filled pores are broken down. The state of compactness, or relative compaction, has important effects on soil properties that determine the playability of turf, both in terms of turfgrass surface quality and subsurface soil strength.

The negative effects of compaction on turfgrass performance arise because of the loss of pores that are normally air-filled. Their conversion to smaller pores physically prevents turfgrass root penetration and leads to anoxia that decreases the biological activity of roots. Finer pores not only hold more water under equilibrium drainage conditions, but also give more resistance to water flow than larger pores. In previous studies, turfgrass plants were shown to concentrate root growth nearer the surface of compacted soils and produce less leaf growth so as to reduce water use.

As it is difficult to assess measures of compaction under a turf surface, most studies aimed at quantifying compaction from a variety of approaches, as such:

1. Compaction relative to a standard

Dry bulk density (DBD) of a soil is a product of the particle volume in a unit volume of soil and the density of those particles. As a soil is compacted, more particles are packed into that volume with less air or pore spaces between the particles. A critical DBD should be definable for a particular profile, above which plant vigor will decrease. The reference point can be found by increasing compaction and compressing pores until very few further pores can be destroyed. This point can be considered the maximum compactibility of that profile and measured DBD in the field can be expressed as a percentage of the reference value. Optimum DBD is relatively lower in profiles high in organic matter. Organic matter can help soil resist compactive loads through mechanisms that affect:

- Binding forces between particles
- Elasticity
- Dilution
- Effects on electrical charge

- Effects on friction

A reference critical relative bulk density of 1.79 g cm^{-3} was derived loamy sand profiles. Plant yields appear to decline sharply above 90% DBD. They inferred that rooting depth had declined regularly as compaction increased because they measured an increase in soil strength that would limit root growth.

2. Pore size distribution and characteristics

The volume and size distribution of pores in a soil sample is an easy indicator of the degree of soil compaction. This information is gained from water release curves from saturated soil cores. Water drained initially from pores with an effective diameter above 75 um is defined as gravitational water by Adams et al (1989). Pores with diameter over 60 um are normally air-filled and are easily penetrated by roots. Pores are classed on the tension required to drain them, which reflect their diameter. Water is successively drained from voids (evacuated under a tension of around 1 kPa), macropores (4-6 kPa), aeration pores (10 kPa), capillary pores (1500 kPa) and residual pores. Readily available plant water is that held in capillary and coarser pores. Under compactive forces, larger pores are broken down, particularly the macropores greater than 50um equivalent diameter, and converted to finer pores. They may also be distrupted so that, although total volumes remain similar, the pore continuity is lost.

Carter (1990) had found a close relationship between macroporosity and relative compaction. Relative yield was reduced below a critical macroporosity of about 11%. In his previous studies, he concluded that a macropore volume of 10% was adequate for functional porosity or permeability but inadequate for optimum soil aeration under humid conditions. Through observation in different racetracks, Murphy and Field (1996) an aeration porosity at field capacity of 10% (v/v) as a minimum for coarse turf surfaces. At this tension, reasonably structured profiles drain down to a state where 90% of pores are water-filled. This corresponds to a macroporosity of about 8%. The value of 10% is often taken as a minimum volume of air-filled pores for turf growing media.

Experimental manipulation of pore size distributions has not shown clear effects on turf quality. Measurements of DBD did not detect compaction relief brought about by tine cultivation (a common maintenance procedure to relief compaction in golf greens and sports fields), they did show up in measures of macropore volumes. The volumes of large macropores (drained between 0 and -1 kPa) were increased by cultivation, more by hollow than solid tines when measured two months after cultivation. The same effect was not evident in smaller macropores (-1 to -10 kPa).

3. Oxygen diffusion rate

Oxygen diffusion rate (ODR) is a measure of the oxygen supply to a point in the soil. It is near instantaneous measure and is affected by air-filled porosity near the electrode and diffusion path to these pores. It therefore gives a good measure of the degree of soil compaction. Bunt (1991) has found that ODR was closely related to air-filled porosity. Carter (1990) stated that root growth of many species is limited at an ODR of 20 x 10^{-8} g/cm^2/min. Murphy and Field (1996) had then reviewed a critical ODR for turf surface is 20-40 x 10^{-8} g/cm^2/min.

4. Water conductivity

Water movement through soils is determined by the size distribution and connectivity of water-filled pores and water-wetted surfaces. Both characteristics are affected by compaction. Water permeability is measured as the hydraulic conductivity (K) at defined soil water potential.

In undistributed soils there is general agreement that large pores or structural elements dominate conductivity near saturation. In Carrow and Weicko's (1989) review, they showed that a characteristic macroscopic radius could be derived from K measurements which indicated the relative contribution of capillary and gravitational components to soil flux. They concluded that a measure of the K function was a good way to determine management effects on soil structure and soil compaction. A general observation is that saturated hydraulic conductivity decreases with depth as DBD increases. Water movement through large pores at saturation is called preferential flow. The preferential flow through large voids is important only near saturation.

Soil compaction, incipient aeration and mechanical impedance stress are known to reduce root growth and function. Greater mechanical resistance and the decreased aeration of compacted soils limit both the length and function of root systems. These limiting soil conditions are generally synergistic and difficult to separate. The study by Carter (1990) was designed to quantify root responses to soil compaction and measure the changes in soil aeration attributed to the presence or absence of roots.

Relatively small increases of bulk density in soil reduced the diffusion rates of soil oxygen. Oxygen diffusion rates measured by platinum microelectrode (ODR) in soils without roots were reduced more than the diffusivity method (measurement gas flow rates) when bulk density increases from 1.1 to 1.3 Mgm^3. Since oxygen diffusion to the surface of microelectrodes is primarily controlled by the film widths of the liquid phase in soil particles, small increases in soil density increased the relative proportion of saturated micropores resulting in greater resistance to oxygen diffusion through the liquid phase. This indicates that ODR is more sensitive to changes in oxygen levels at lower bulk densities while gas diffusivity measurements are more useful in changes in oxygen status of soils compacted to a higher bulk densities. Test results shown that root length has accumulated on the less compacted surface area than the compacted subsurface.

Apart from bulk densities, soil water content also has significant influence on oxygen diffusion rates. Studies by Stolzy and Letey (1964) have shown that a significant reduction in oxygen diffusion rate is observed with the increase in soil water above 60 percent saturation and bulk densities above 1.25 Mg m^{-3}. The interaction of water and bulk density was also found to be significant. The compaction of soils reduces proportion of large pores in the soil. Gaseous diffusion, which is a continuous process, is greatly influenced by the proportion of soil pores which are air-filled. For adequate aeration of the profile, these pores should be continuous over the diffusion path. Water, while entering in the soil, not only displaces the air but also obstructs gaseous diffusion. The oxygen content in wet soil is limited because oxygen diffusion rate through water is 10^4 times lower than through gases. The level of soil water at which the oxygen diffusion rate decreases below a certain threshold is therefore very important to plant growth.

When water enters soil pores, it displaces not only air but also obstructs gaseous diffusion. ODR decreases abruptly when a soil reaches saturation by water. Secondly, ODR decreases as the water content increases because of diminution in the volume of air-filled pores and lengthening of diffusion path to the electrode. Thirdly, at high wetness values, soil often contains isolated pockets of occluded air which though forming part of air-filled volume, do not contribute to active gaseous exchange. As soil water content decreases from saturation, ODR increases due to a decrease in length of the liquid path between air-filled pores and the electrode of meters.

3.5 Significance of Macropores

The amount and organization of macropore space (pores greater than 30 um dimension) have been recognized as important to the behaviour of soil profiles. The connectivity and dimensions of macropore space can influence water movement and gas movement. Exploration of the soil by roots can also be influenced by the extent and dimensions of the macropore space. Major functions of macropore space are fluid storage and provision of spaces for root exploration. Water movement in macropores does not follow capillary theory because of macropore size, which allows film flow along the wall of a pore not completely filled with liquid. Macropores contribute to rapid water flow (bypass flow) in the pores with little or no water flow through the soil matrix. Transitory ponding allows water movement into macropores open to the surface even when the bulk soil is not saturated. Results by Blackwell et al showed that it is evident that intrinsic permeability to air and saturated hydraulic conductivity is more sensitive to changes in the amount of pore spaces than their organization. It has been recognized that measurements of air permeability and hydraulic conductivity can reveal extremely small changes of soil conditions caused by compaction. Research on plant and root growth on soils has found that 8% to be the lower limit of air-filled porosity for root growth unrestricted by oxygen supply. When porosity is lower than 8%, root growth has been noted to concentrate along channels and fissures. Thus, the limits for root growth also maybe defined in terms of a limiting value of intrinsic permeability or vice versa.

3.6 Water Retention

Sports turf profiles are subject to frequent use and traffic, often under the most adverse of soil strength condition. This poses difficult soil problems for turf managers as the soil and profile structure is continually broken down, resulting in lowered water infiltration and oxygen rates and sluggish internal drainage. Soil layers of distinctly different properties can dramatically affect soil water relations. When a finer-textured layer of soil/sand is underlain by a coarse-textured layer, water retention in the finer layer is increased, compared to a uniform profile. This results from the fact that coarse-textured layers will not transmit significant amounts of water unless the soil water matric potential is near 0 kPa (saturation). Thus the overlying layer of material must be nearly saturated before significant amounts of water enter the coarse-textured layer. Once the soil water matric potential is high enough to cause water flow in the coarse layer, water moves rapidly within the coarse layer. As the profile drains, the coarse layer stops conducting water at relatively high matric potentials, and water retained in the overlying layer remains higher than in a uniform profile.

In the field of sports turf, the term "perched water table" is used to describe the effect coarse-textured layers have on water relations of the soil mixture in the rootzone layer. It is also the essence of success of our sand mesh turf track which is basically a layer of sand on top of a coarser layer of gravel. This will provide a profile with fast drainage and yet will be able to hold sufficient moisture at the top.

Results by Taylor et al (1991) on water retention in profiles with different textures showed that during a 48-hour drainage period, initial drainage from the profiles was rapid in all types of sand/soil mixtures, with matric potentials measured at the 20 mm depth falling to less than -2.0 kPa within 1 to 3 minutes of the removal of surface water. This initial rapid drop in matric potentials was followed by a gradual decrease in matric potential energy through the remainder of the drainage period. At the fine/coarse-textured layer interface, the matric potential energy at which drainage becomes negligible is determined principally by the coarse-textured sublayer and not by the root zone mixture. If the root zone layer mixture does not drain any water at the matric potential established by the coarse-textures layer, the lower portion of the root zone is likely to remain saturated for extended periods of time. Careful selection of both root zone mixture and subsurface layer components is critical to avoid drainage problems in sports turf soils. Gravel sublayers will move water to drains quickly once water begins flowing in the gravel, but they also maximize the retention of water in the root zone above the gravel.

The upper bound of storage of water in the root zone layer, termed 'field capacity' is an elusive quantity since the dynamics of the whole profile influences its value. Clothier and White (1981) has shown that using the water retention curve of a soil, it is possible to predict the water content profile at the cessation of drainage. Good agreement has been obtained between field measured and predicted water content profiles for studies done in New Zealand. He has concluded that the storage capacity of layered soils maybe inferred solely by determination of the moisture retention curve of the overlying root zone layer and the field measurement of the steady state pressure potential in the coarse layer after drainage has ceased.

3.7 Ideal sand medium

Based on Gibbs et al (1983) the following set of ideal characteristics for a sand based turf profile (Table 3.2) are set and are used to evaluate the performance of our tracks

Table 3.2 – Physical properties of an ideal sand medium profile

Bulk density	1.2-1.6 g cm^{-3}
Porosity	40-55%
Macroporosity	20-27%
Air-filled porosity at -40 mb	>15%
Air-filled pores 5cm	>10%
Water-filled pores	50%
Water holding capacity	22-26%
Organic matter	<4%

CHAPTER 4

METHODOLOGY

4.1 Study Site

The Shatin and Happy Valley turf tracks are sampled for the study on physical properties of sand on racetrack performance.

1. To study the effect of age on the physical properties and its influence on track performance, 6 sections on the Shatin Racecourse were chosen (Figure 4.1). All of these sites are along the oval of the main turf track and are the main racing strip. These sections were constructed and re-constructed at different times as shown in Table 4.1, hence, the profiles are of different ages.

Table 4.1 – Year of reconstructions in Shtain Turf Track

	Site location		Year of construction	Group
1	Stable Bend – old	SB	1989	I
2	Home Straight – new	HSN	1997	III
3	Back Straight – old	BSO	1990	II
4	Back straight – new	BSN	1998	III
5	Home Bend	HB	1996	III
6	Home Straight - old	HSO	1990	II

As the Shatin Racecourse is not shaded by buildings nor surrounded by high-rises or mountain, the whole track grows under similar environment with little variations in terms of climatic factor.

2. The Happy Valley turf track was reconstructed in 1995, therefore the tracks is of uniform age except for two trial sections which were built again in June 1998 using a new sand mesh design (Figure 4.2). These trial sections are at the winning post and at the back straight. The two sections were built according to new profile design that is a modified sand mesh system designed by StrathAyr. This revised profile (265 mm) is shallower than the original profile depth (350 mm) but with similar principal behind the design.

   Data on old and new profile will be used to study how profile depth affects growth and performance, whether getting a profile depth designed to suit the sand used by construction will override the importance of waiting for a track to mature to its optimum age and optimum performance.

3. Apart from these new test strips, there is also a drawback in terms of grass growth. Due to the orientation of the racecourse and the close proximity to high-rise buildings, half of the racetrack, namely, the home straight is shaded by the 10-storey grandstand in the afternoon. Hence, this section of the track does not receive any direct sunlight in the afternoon and are depending solely in the morning sun (Figure 4.3).

   Comparing data from the shaded home straight and the non-shaded back straight could then evaluate the influence and dominance in how the amount of sunlight received affect the track. Comparison between the two racecourses will not be made due to the differences in growing condition, usage intensity, management practices and purposes.

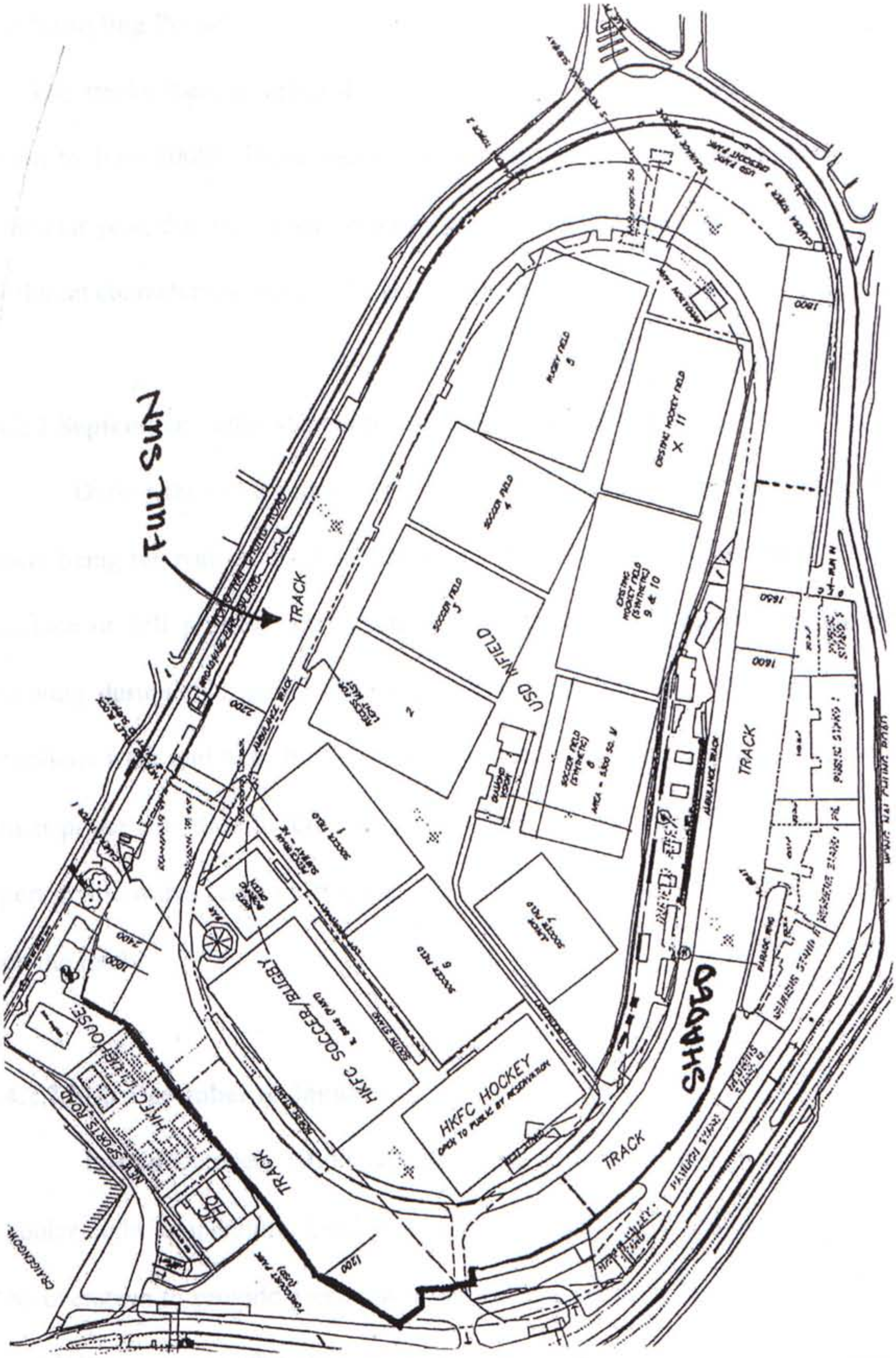


Fig. 4.3 - Site 3 - The Shaded Section of Happy Valley

4.2 Sampling Period

The tracks were sampled 4 times during the period of study (December 1998 to June 2000). These samplings were not evenly distributed across the calendar year, that is, not sampled every 3 months, but were spaced to capture different characteristic period of track performance.

4.2.1 September - after the commencement of first race

During the off seasons (from mid-June to late August) the turf tracks were being renovated, which included physical renovation, replacement of turf surface or full profile reconstruction. In addition, there was no racing and training during this period. The tracks have abundant time to recover from previous wear and tear. In the opening of season, the turf tracks should be at their prime condition in terms of grass growth and physical properties. In this period, the warm-season turf grass, Tifton-419, would be the dominant species on the track.

4.2.2 Mid-December to January

In mid-October, Tifton growth would slow down due to progressively cooler night temperature. Cool season grass, mainly perennial rye grass would be oversown to provide green cover and surface strength. Rye grass would not reach its prime growth until mid-December or January when most Bermuda is dormant. During this period, there would be no racing at Christmas and some light physical renovation works would be conducted. Since this was the dry period, profile hardness would usually be the biggest concern.

4.2.3 April

The progressively warm day time temperature in mid-March marked the beginning of the transition period. This is the period when perennial rye grass begins to die due to the warm temperature. However, Bermuda is just beginning to pick up and resume active growth. Since Bermuda growth at this period is still slow, the track is in a fragile stage. Apart from weak turf growth due to the transition weather pattern, after 7 months of racing, the track is beginning to show signs of deteriorating physical condition. Hence, April and May are the most difficult months for the track.

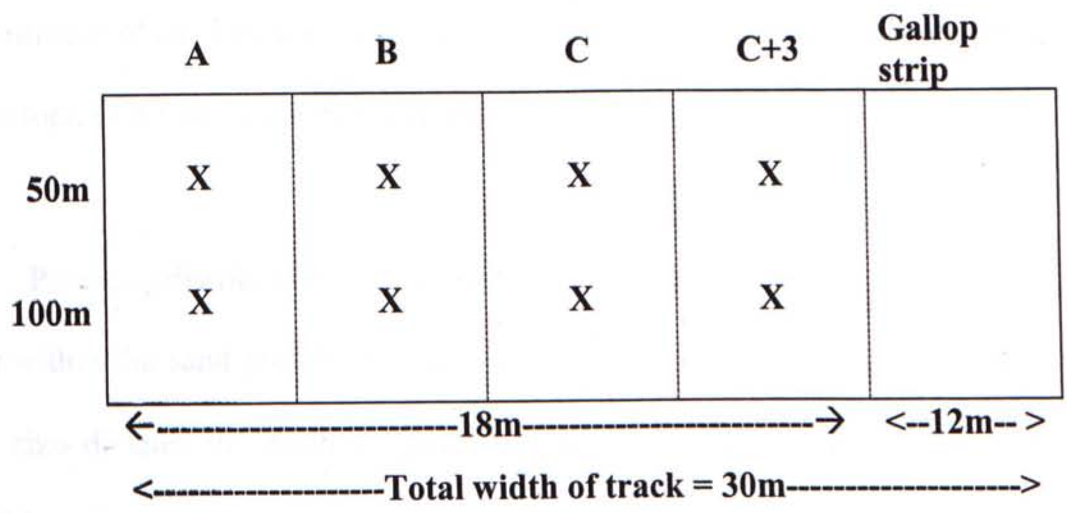
4.2.4 June, before the on-set of summer renovation

The condition of the track in June will determine the intensity of summer renovation and dictates the track condition of the following season. It is important to sample at the end of the season to measure the cumulative effect of constant racing and the effectiveness of light on-season renovation. During this period, most of the ryegrass has already die and the track will be a monoculture of Bermuda.

4.3 Sampling Method

In each sampling section, approximately 150 m in length, 8 sample points were marked at 50 m and 100 m along the length of the sections. This was to encounter any possible local variations along the length of the section. To account for variations across the width of track, samples were taken from A, B, C, C+3 course[6] to spread out across the width of racing strip. The outer 12m of the track were not sampled. This was the gallop strip mainly used for morning trackwork and was not normally considered as the racing strip. In addition, this strip would experience more intensive wear (3 gallops per week) than the racing strip and higher vehicle traffic, hence resulted in different wear patterns and maintenance requirements.

Fig 4.4 - Layout of sampling area



In each sampling point 2 sand cores was taken. One core with diameter of 60mm, was taken at depth 35-70 mm below grass surface to measure the moisture release curve. A second larger core (diameter 96 mm) was taken at the surface to be used for measuring hydraulic conductivities and biomass. Apart from soil samples, other parameters such as clegg hammer readings, penetrometer readings, shear vane measurements, oxygen diffusion rates and divot assessments, were also measured in situ. Most track performance indicators, as listed below, were measured on site.

4.4 Physical Qualities of Sand

4.4.1 Moisture Release Characteristics

Sand cores of 60mm diameter were taken at depth 35 –70 mm below track surface to eliminate the effect of thatch and organic matter enriched layer. With a metal corer, the sand was left intact within the sampling tube. The sampling depth was chosen to eliminate the effect of thatch layer on the performance of sand system. In each sampling point, one sand core was taken, thus a total of 8 samples were taken from each section.

Pore size distribution is a description of the number of pores of different sizes within the sand profile. This is a very useful characteristic of the soil as pore size dictates the drainage properties of the profile as well as aeration condition. To measure pore size, the moisture release method was used. In this method, the basic theory was that "the volume of water released by an increase in matric solution from one tension to another equals the volume of pores having an effective diameter between d_1 and d_2 where

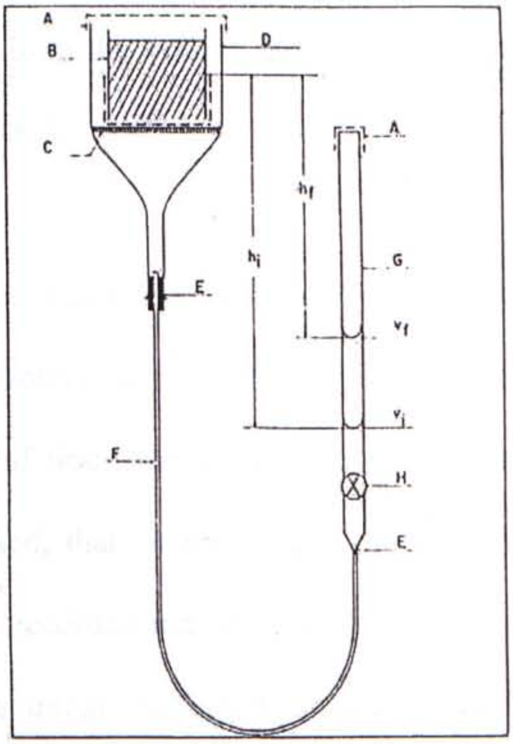
---

[6] A, B, C, C+3 course indicates the width of racetrack. A is the full width of 30m. For B, C and C+3course is 26m, 22m and 19m wide respectively.

$$d = \frac{4\sigma}{\rho g h}$$

σ = assumed particle density of sand
ρ = dry bulk density
g = gravitational force
h = height of water column

As tension on the core increases, water was drawn from progressively finer pores. The volume of water released at very low tension (10 – 50 mb) indicated the amount of macropores whereas the volume released at high tension (50 – 100mb) represented micropores. The Buchner funnel method (Smiths and Mullins 1991) was used with the set up shown (Figure 4.5):



A = Aluminum foil covers.
B = Sample in cylinder with cheesecloth bottom. Volume, V_s. (Omit cheesecloth for suctions >150 cm. of water.)
C = Fritted glass porous plate (part of D).
D = Büchner funnel with porous plate.
E = Joints must be secure.
F = Flexible tubing.
G = Burette, least division not more than 0.1% sample volume.
H = Stopcock of burette.
h_i = cm. of water suction, initial.
h_f = cm. of water suction, final.
v_i = Burette reading, initial.
v_f = Burette reading, final.

Figure 4.5 – Buchner funnel method

Using core samplers of known volume, after sand cores were taken from the track with the core sampler intact, the ends of the sample were trimmed to ensure a known volume of sand was within the core. The sample was weighed and then placed directly on the porous plate. A thin layer of dry sand was spread on the plate to ensure a good surface contact. With the sample in place, water was added into the funnel until free water stands around the sample to the soil surface. The soil was allowed to stand immersed in water overnight or for more than 8 hours until full saturation. After the sample was completely saturated, the excess water was removed with a small pump. To reduce evaporation loss from the system, the funnel and the open end of the burette were loosely covered.

The burette water level was positioned level with the porous plate to obtain an initial volume of water in the burette. The burette was then lowered during drainage of free water as needed to maintain the pressure differential. When flow ceased, that is when water level becomes constant, the burette reading (V_0) was recorded and the burette was lowered 10 cm below the porous plate. As in the initial reading, the burette was lowered to adjust for the released free water and reading was recorded when the water level became constant again. This process was continued for tensions at 20, 30, 40, 50, 75, and 100 cm. As the tension was increased, the time allowed for drainage was also increased. This was because as tension increases, water was being drained from progressively smaller pores and pores were getting more difficult to drain due to increased capillary forces that held on to the water. Because of this nature of pore action, tension increments were made relatively small at low tensions (10 cm increments for tension 0 to 50 cm) and the increment increases with tension (25 cm for tension 50 to 100 cm). On completion of the series of moisture release, sample volume (V_b) and final sample weight (M_w) was determined.

The calculation of results:

1. The drained sample was oven dried at 100-110°C for 10 hours to obtain the dry weight. Bulk density was calculated,

$$\text{Bulk density} = \frac{\text{dried sample mass } (M_d)}{\text{dried volume of sample } (V_b)}$$

2. Organic matter content, represented as a percentage by weight of organic matter in the sand, was obtained from a sub sample of each core. The sub sample was combusted at 600°C for 6 hours and the percent weight loss during this process was noted as the organic matter content.

$$\text{OM content} = \frac{\text{dried weight} - \text{residual weight}}{\text{dried weight}} * 100\%$$

3. Water content at sampling was the field moisture expressed both on a weight (FMW%) and a volume (FMV%) basis. This parameter was very useful in estimating race day going as going and race times were closely correlated with profile moisture level.

4. Total porosity, the percent of volume consisting of space (pores) between particles, was calculated with an assumed particle density (2.65 g/cc) and bulk density:

$$S_t = 100\left(1 - \frac{\text{bulk density}}{\text{particle density}}\right)$$

5. Total air filled pores, S_{100}, was the percentage of the soil volume occupied by air space at the highest tension employed.

$$TAP = S_{100} - \frac{\text{volume of water loss in drying}}{\text{volume of sample}} \times 100\%$$

6. Macroporosity was the air filled porosity at a tension of –50 mb, that is pores with diameter greater than 60um. These pores were expected to be filled with air under normal drainage conditions.

4.4.2 Saturated hydraulic conductivity

Eight surface sand samples of radius 96mm and depth 90mm were taken from each sampling section. Topgrowth from samples were removed and saved for biomass measurements. The bottoms of the samples were trimmed to adjust the level of sand to about 15-20mm below the rim of the sampler. This was to give room for the constant head of water to be placed above the sample. After trimming, the bottom was secured with cheesecloth which was water permeable but the pores were small enough to refrain any loss of sampled material. Sand cores were then immersed in water to allow for saturation overnight or at least 4 hours to allow for full saturation.

For ease of measurement and to minimize the amount of equipment required, the infiltration method was adopted to determine the saturated hydraulic conductivity (Clothier and White 1981). The infiltration theory showed that the infiltration rate from a ponded surface into a vertical column of uniform porous material would eventually approach a constant rate, equal to the hydraulic conductivity of the saturated material. The approximate Green and Ampt theory of infiltration gave the infiltration rate di/dt when the wetting front has advanced to a depth Z as

$$di/dt = K\,[hf/Z + 1]$$

where in this case K was the flow rate pouring into the soil sample in ms^{-1}, hf was the soil water pressure head i.e. the depth of water head, and Z was the depth of the soil sample. Hence, to measure saturated hydraulic conductivity, known amount of water was being poured into the soil sample until a constant infiltration rate has been reached.

4.4.3 Unsaturated Hydraulic Conductivity

The same samples used for measuring saturated hydraulic conductivity were used for measuring the unsaturated hydraulic conductivity. Fresh clean sand with the same particle size distribution as the sand used for track construction was used for topping up the sand samples to the rim of the sampler to give good contact to the disc permeameter (Fig 4.6).

Unsaturated hydraulic conductivity was a measure of macropore flow at different water potentials, potentials less than zero. The more negative was the water potential, the smaller the maximum diameter of pores that could participate in flow from the soil surface. Under this circumstances, an understanding of different flow rates would give a vivid picture of macropore size distribution within the soil can be achieved. Unsaturated hydraulic conductivity was also important in characterizing how the track surface would behave at the initial state of a downpour before the track profile was saturated. To conveniently measure unsaturated hydraulic conductivity, disc permeameter developed by Clothier and White (1981) was used a three different water potentials, -100mm, -40mm and –20mm.

In this set up, water potential was determined by the bubbling pressure of a capillary needle through which air entered the water reservoir. Water was supplied to the sample via a glass plate of appropriate bubbling pressure. To adjust the bubbling pressure, it is only needed to adjust the height of water in the bubbling tower. As the tower of water reservoir was also calibrated, it was easy to keep track of the amount of water flowing through the system at a specific set of time. To determine unsaturated hydraulic conductivity at a certain potential, for instance, -100 mm, a whole reservoir of water was allowed to bubble through the sample to ascertain the sample was at the set water potential. With a refilled reservoir, water was allowed to bubble through again, the amount of water left in the reservoir (r_0) and the time (t_0) between each reading was recorded.

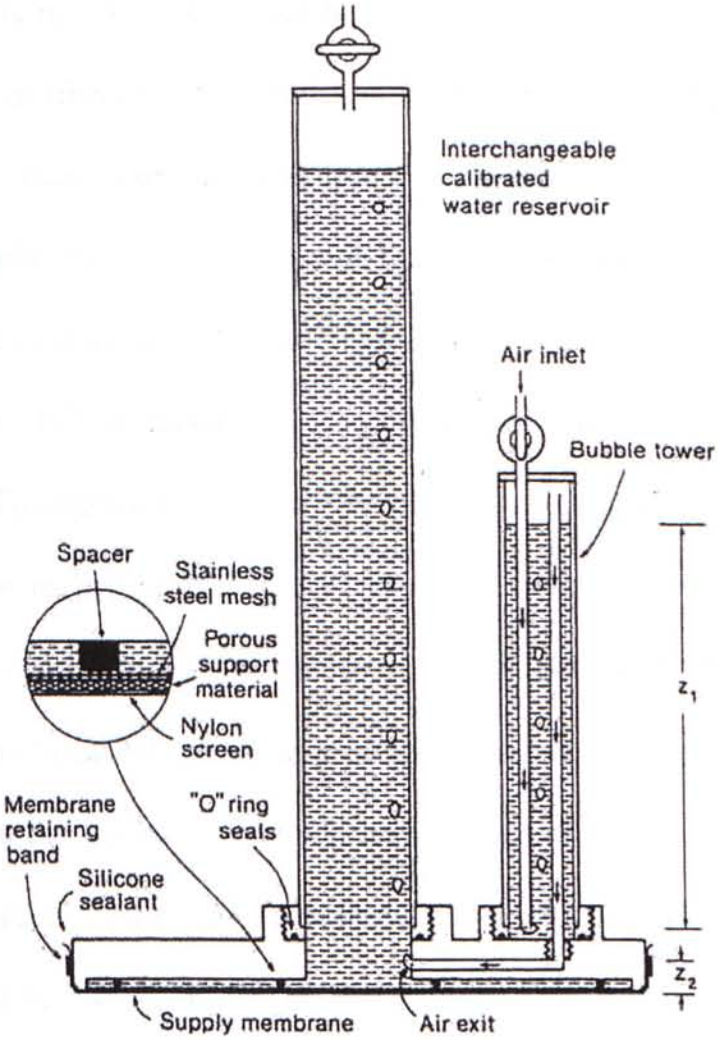


Fig. 4.6 Setup of Disc Permeameter

Flow rate was determined by

$$K = r_0 - r_1 / t_1 - t_0 \text{ (ml s}^{-1}\text{).}$$

As stated in the infiltration theory, flow rate was recorded until a constant flow rate was achieved. The resultant hydraulic conductivities were plotted against the water potential to give a profile of the characteristic unsaturated hydraulic conductivity for each section.

4.4.4 Oxygen Diffusion Rates

Oxygen is required by all aerobic forms of life. An understanding of oxygen supply mechanism is essential in understanding an organism's life processes. Since there is no supply of free flowing oxygen in soil, plants must obtain their supply of oxygen by diffusion through a moisture film surrounding soil particles. As diffusion in liquid is much slower than in gaseous form, in most cases the limiting factor for oxygen supply is diffusion through the moisture film. To characterize soil oxygen conditions, oxygen diffusion rate is the factor to be measured. The use of platinum microelectrode to measure oxygen diffusion rates in soils on site was first introduced in 1952 and this method had then be widely used. In principle, when an electrical potential is applied between the platinum electrode inserted in soil, oxygen is reduced at the platinum surface. During this reduction process, electrons are involved and hence a current is produced. This electric current which flows between the electrodes is proportional to the rate of oxygen reduction. The rate of reduction is in turn related to the rate at which oxygen diffuses to the electrode. By measuring this current it is possible to measure the diffusion rate (Stolzy and Letey 1964).

In this study, the Jensen 10 electrode oxygen diffusion rate meter was being used. In each sampling section, 4 sets of 10 readings were taken. For each set of 10 readings, 5 readings were taken at 50mm below ground surface and another 5 at 100 mm below surface. This was to observe the possible differences in supply of oxygen at different depths. From previous experiences with the oxygen diffusion rate meter and from studies by Stolzy and Letey (1964), to have reliable results from platinum microelectrode, the entire surface of the electrode must be submerged into the soil and be covered by a moisture film. Although oxygen diffusion rate was expected to increase with decreasing soil moisture, when soil moisture decreased to a point where there was not enough moisture to cover the microelectrode, measured oxygen diffusion rate would become extremely low and readings would be unreliable. To minimize measurement error, oxygen diffusion rate was measured after the track was irrigated and drained till field capacity. Soil samples were also taken to determine the actual soil moisture content.

4.5 Grass Biomass

4.5.1 Topgrowth, Stolons and Roots

When preparing soil samples for measuring saturated and unsaturated hydraulic conductivity, topgrowth was being trimmed off from the samples. Extreme care was taken that only grass blades were removed, with stolons and rhizomes still intact. To remove moisture from topgrowth, collected grass blades were dried in the oven at 100-110 °C for 10 hours to reach a constant dry weight. Dry weight of grass blades from each sample was then measured and recorded. As there are 8 soil samples from each section, there were 8 sets of biomass per section.

The measurement of stolon and root mass was more laborious as a direct measure approach was adopted. After soil samples were used to measure hydraulic conductivity, sand was being carefully washed off to retain the stolons and root system. To minimize the loss of root system, a coarse sieve was used to hold the sample in place while a continuous stream of water ran through the sample to slowly wash off all sand particles. With the retained stolons and root system, roots were being separated from the stolons. The collected stolons and roots were then oven dried separately in the same method as the topgrowth to measure their dried weight. Care was taken to remove sand particles as thoroughly as possible since sand particles are much heavier than roots. Any left over sand particles could significantly affect the resultant root mass.

Direct root mass measurement was extremely time consuming, however, no special equipment was required as compared with other methods, and previous studies done by AgResearch had shown a significant relationship between root mass and surface strength, hence, this method was adopted. Several references have suggested the measurement of total root length, however, in light of the growing habit and characteristics of the racetrack grasses, this method was abandoned. In general, rooting depth of plants is very important to plant vigour and of research value. In this case, rooting depth was not considered, as most of the galloping action is on the top 3" of the profile. If the top 3" could provide enough strength and roots to withstand the action of horses, the track has a very good chance in supporting the racing fixture.

4.6 Performance Indicator

4.6.1 Track Hardness

Track hardness was measured on site in two ways, using a penetrometer and using a Clegg hammer. Both instruments gave similar results but work in different mechanical process. The penetrometer is developed in France and widely used in racecourses internationally. It is basically a graded metal square rod with a 1kg metal weight attached. The metal weight is dropped to hammer the square rod into the track surface. Firmness is evaluated by the depth of the rod is driven into the track by the first, second and third drop of the weight. For racing, only the depth of the first drop was used in evaluating track going on race days. This was because most of the action was on the top 2" of the track. However, the second and third drop was useful in predicting subsurface support and detecting compaction layers in the sand profile. In this study, all three drops were used in evaluating track hardness and penetration resistance. The relationships between the three drops were also studied to determine the importance of these reading in predicting and evaluating track performance.

The Clegg hammer is another instrument developed to measure track firmness in a different way. The Clegg hammer consists of a weight of 500 g and a sensor. The weight is dropped from the height of the Clegg and the sensor measures the deceleration of the weight as it hits the track surface at the time of impact. The harder the surface, the faster it decelerates and a higher reading is recorded. A higher reading yields harder grounds as oppose to the penetrometer where softer ground is easier to penetrate and gives higher readings.

Track hardness was measured by both of the mentioned instruments weekly before racing and quarterly during the sampling period. During the weekly sampling, readings were collected for racing purpose, therefore, only that meeting's racing strip would be sampled. In addition, only two readings were collected every 200 m along the track oval, thus only 2 drops from each section. The full width of the racing strip would be covered in approximately 4 weeks as the rails were progressively shifted outwards. Owing to the Club's operation, penetrometer readings were taken at 4 am whereas Clegg hammer readings were taken at 10:30 am. Some changes of track going have been observed during this time lag but results of these readings were still highly correlated. In regard to the low sampling intensity of these data, they were only used as additional reference information. In the quarterly data collection, track hardness data were collected more intensively. For both instruments, 32 readings were taken from each section in a zigzag line quadrant to capture the possible variations within each section.

As track hardness was directly affected by soil moisture, readings were taken at field capacity when the track ceased to drain. Readings wiould not be taken during wet weather to eliminate the rain effect nor immediately before irrigation to ensure that the track was not excessively dry.

4.6.2 Shear Strength

The strength of soil would affect its behaviour in load bearing, proneness to compaction, ease of root penetration and susceptibility to failure when impacted (Marshall et al 1996). Shear strength describes the stress required for failure to occur. And failure is when stress occurred exceeds strength of the soil and fails by fracture or plastic flow. This could account for the strength of the sand profile and the grass growth on the surface. Since strength is measured on the surface, shear of the grass cover is inseparable from the final measurement.

A 20mm x 40mm metal shear vane was used for the measurements. The full length of the vane was pushed into the sand and torque was measured when the rod to which the four vertical blades were attached was rotated to shear the sand. As with track hardness readings, 32 readings were collected from each section. Similarly, moisture content would strongly affect shear strength. The track was brought to field capacity to reduce the variation in moisture content over the track as suggested by Marshall et al (1996). It was undesirable to measure strength when the track was either too wet or too dry. This was because sand particles become flowable at extremely low or high moisture content. Strength would initially increase with moisture content, but beyond the plastic limit, soil would fail due to plastic flow. Therefore, moisture content at times when shear strength was taken was noted as well.

4.6.3 Divot Assessment

After each race meeting, the racing strip, 5m from the inner running, was sampled for the amount of divots in each studied section. The amount of divots was one of the best indicators to evaluate how well the track stood up to the gallop of over 100 horses in each race day. This was a direct measure of how the track performed for its building purpose. However, divoting is the combined effect of grass strength and the support from sand.

To sample for the percent of turf damaged by horses, 1m x 1m square grid was used. This $1m^2$ grid was further divided into 100 squares, 10cm x 10cm each. Each sampling section was divided into two halves, one section being 0-2m from the rail and the other 2-5m. This was to encounter for the fact that horses have the tendency to lean onto the running rails when they gallop. Hence, the inner section wiould experience more damage that the outer. Only during wet weathers when the inner rails were churned up will horses gallop out to the drier and firmer grounds on the outside.

In each section, the grid was thrown randomly 3 times to cover the whole length of the section. In each throw, the number of squares without grass cover, that is a divot, was noted. Since there was a total of 100 squares in the grid, the number of squares with bare ground was then conveniently converted to the percent of divoted turf surface on the whole turf section. As rails were being progressively moved outwards for each race day and then back to the original 'A' position, the full width of the racetrack was then sampled after 4 weeks of racing.

This sampling method was developed in an Australian racecourse and brought into the Hong Kong Jockey Club by the previous Grass Tracks Consultant, Mr. Tony Field, in 1997. This method was simple and direct but could give a vivid picture on wear tolerance of the track

CHAPTER 5

THE STUDY OF PERFORMANCE INDICATORS AND PROFILE PHYSICAL PROPERTIES

5.1 Performance Indicators

5.1.1 Race Times

Race times are very good indicators of track performance, when the turf track is at its best condition, horses will perform at consistent and predictable race times without putting excessive stress on their tendons. This is usually associated with a track rating of 'Good' or 'Good to Firm' where race times will be near or just a fraction faster than standard times.

Standard times are average race times calculated based on the class or ratings of horses for all the major distances raced in Hong Kong. Each racetrack has its own set of standard times. Only race times raced on 'Good' and 'Good to Firm' track are used, as these track condition are considered favourable and desirable to allow horses to perform to their fullest capacity. The current season's standard times are calculated based on results from the previous season. To maintain a consistent racing surface, it is therefore necessary to identify the range of each performance indicator (shear strength, vertical penetration resistance, surface hardness and percent divoting) to simulate a track that will always race near standard times. The average deviation of standard times over every 200m (sec/200m) is a good sign of whether the track is performing better or inferior to standard.

$$\text{Average deviation from standard time} = \frac{\text{Actual race times} - \text{standard time}}{\text{Distance race} / 200\text{m}}$$

A positive deviation shows that the average race time is slower than standard, whereas a negative deviation shows that times are faster than standard. Currently, race times and their standards are only available and applicable to the entire length of the race and the track, but not to the individual sections of the track. Thus this section will focus on the track at its entirety.

Table 5.1 - Standard times for Shatin Turf Track

Class	Premium	1	2	3	4	5	griffins
1000m	0.56.8	0.56.8	0.57.0	0.57.5	0.57.7	0.58.2	0.57.9
1200m	1.09.3	1.09.6	1.10.2	1.10.4	1.10.6	1.10.8	1.10.7
1400m		1.22.6	1.22.9	1.23.1	1.23.4	1.23.6	1.23.3
1600m	1.34.6	1.35.2	1.35.9	1.36.1	1.36.4	1.36.7	
1800m		1.48.7	1.48.9	1.49.1	1.49.3	1.49.9	
2000m	2.02.2	2.02.4	2.03.3	2.04.0	2.04.0	2.05.3	
2200m		2.15.8	2.17.1	2.18.3	2.18.6		
2400m	2.27.6	2.27.6					

Table 5.2 - Standard times for Happy Valley Turf Track

Class	Premium	1	2	3	4	5
1000m			0.57.7	0.57.9	0.58.1	0.58.5
1200m	1.10.1	1.10.4	1.10.6	1.10.8	1.11.1	1.11.3
1650m		1.40.9	1.41.4	1.41.7	1.41.9	1.42.3
1800m		1.50.8	1.51.0	1.51.2	1.51.6	1.51.8
2200m			2.18.9	2.19.1	2.19.8	2.20.0
2400m				2.32.7	2.33.0	

Source: Hong Kong Jockey Club

As the pattern of racing is different for Shatin and Happy Valley racecourse, a different set of optimum ranges will be developed for each racecourse.

5.1.2 Shear Strength

When exploring the relationship between deviations from standard times with profile strength, a strong correlation is obtained in both tracks. Correlations on both tracks are significant except for Shatin in the season of September 2002 to June 2003. Poor correlation in Shatin 2002-2003 was due to a change in personnel for taking value which lead to some inconsistency in values collected.

Table 5.3 - Correlation between deviation from standard times and profile shear strength (r^2 values, $p <= 0.05$)

Season	Happy Valley	Shatin
1999-2000	0.494	0.492
2000-2001	0.407	0.495
2001-2002	0.498	0.478
2002-2003	0.758	0.233

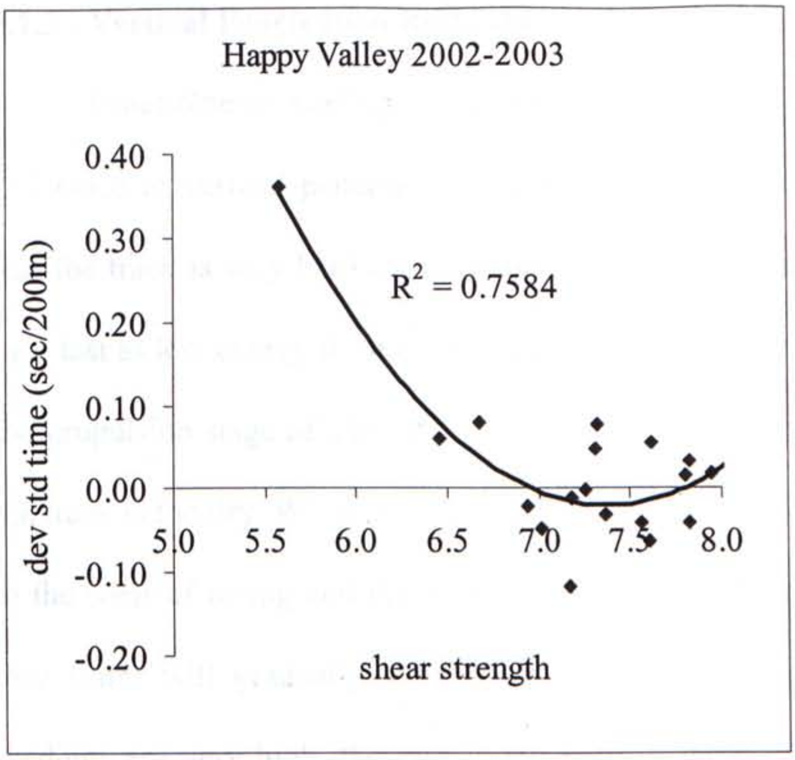
The correlation is stronger in Happy Valley because the tracks is relative younger. It has less accumulation of organic matter in the profile to glue the profile together and the degree of compaction is lower, thus profile strength plays a very important role in determining track performance.

For a typical Good to Firm track, average deviations of race times from standard times is in the range of +/- 0.05 sec/200m, the desirable range of shear strength for both tracks are then derived:

Table 5.4 - Desirable range of shear strength (kPa)

Season	Happy Valley	Shatin
1999-2000	6.28 – 6.30	6.70 – 7.15
2000-2001	6.60 – 7.50	6.60 – 7.20
2001-2002	6.45 – 7.30	6.65 – 7.45
2002-2003	7.00 – 7.80	8.30 –10.00
Average	**6.58 – 7.23**	**7.06 – 7.95**

As the racing pattern in Shatin is less damaging to the track, the general shear strength in Shatin is higher than Happy Valley. The total length of the Happy Valley track is only 1400m, any races from 1650m onwards need to circle the track more than once and long distance race such as 2400m is close to 2 laps. This has put extra pressure onto the track surface with greater divot damage and more recovery to catch up, hence profile shear strength is lower under similar conditions to Shatin. Whereas, the total length of Shatin is 1900m and it has two extension chutes, thus most distances raced will only required to circle the track once. It should be noted that owing to this phenomenon, the standard times in Happy Valley is slower than Shatin.



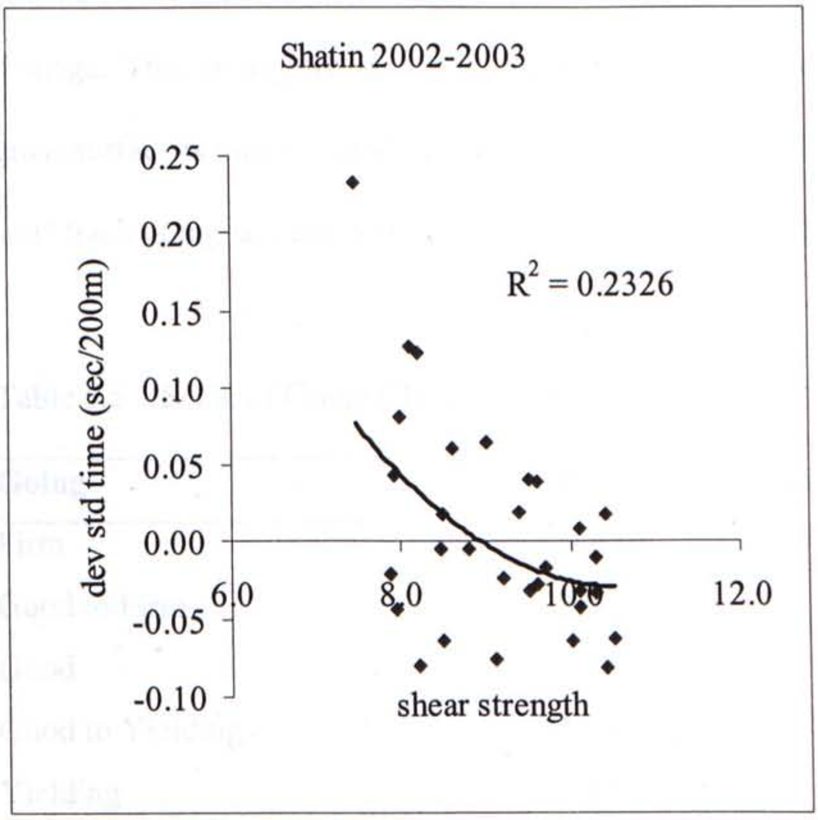


Figure 5.1 - Correlation between deviation from standard times and profile shear strength

5.1.3 - Vertical Penetration Resistance and Hardness

Penetrometer reading is an indication of both surface hardness and resistance to vertical penetration. When readings are very low, this indicates that the track is very hard and difficult to penetrate. It is expected the track to race fast as less energy from the horse is wasted or absorbed by the track during the propulsion stage of a horses' gallop. However, this could also indicate that the track is too dry. When the track is dried up, the profile might fail to hold up to the wear of racing and the surface will start to fall apart. When his occurs, race times will gradually slow down. On the contrary, when penetrometer readings are very high, the race is relatively softer with more give and divot damage. This is usually associated with conditions of wet weather or when grass surface is thin and could provide little resistance to damage.

Turf track going is rated during race days based on the following scale:

Table 5.5 – Scale of Going Classification

Going	**Penetrometer reading**
Firm	< 2.50
Good to Firm	2.50 – 2.75
Good	2.75 – 3.00
Good to Yielding	3.00 – 3.25
Yielding	3.25 – 3.50
Yielding to Soft	> 3.50
Soft	Racing under rain
Heavy	Racing under heavy rain

The correlation between deviation from standard and penetrometer readings is strong, except for the season 1999-2000:

Table 5.6 - Correlation between deviation from standard times and penetrometer readings (r^2 values, $p<=0.05$):

Season	Happy Valley	Shatin
1999-2000	0.327	0.143
2000-2001	0.667	0.634
2001-2002	0.300	0.629
2002-2003	0.417	0.417

For the range of +/- 0.05 sec/200m from standard time, the desirable ranges of penetrometer readings for both tracks are as follow. As the correlation for 1999-2000 is insignificant, desirable ranges are not included.

Table 5.7 - Desirable range of penetrometer readings

Season	Happy Valley	Shatin
1999-2000	Not available	Not available
2000-2001	2.62 – 2.68	2.60 – 2.68
2001-2002	2.63 – 2.59	2.64 – 2.73
2002-2003	2.59 – 2.68	2.65 – 2.77
Average	**2.61 – 2.65**	**2.63 – 2.73**

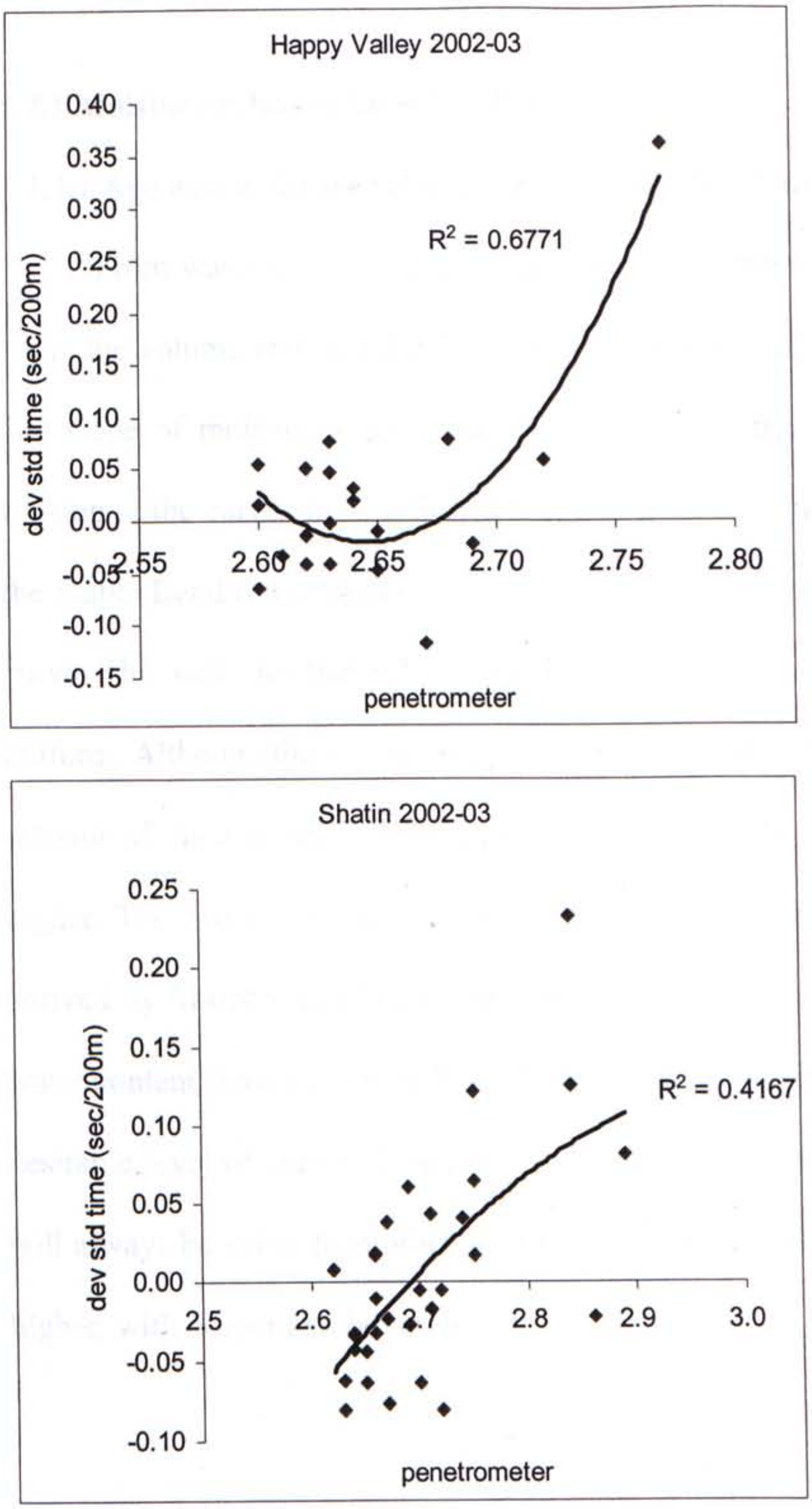


Figure 5.2 - Correlation between deviation from standard times and penetrometer readings

5.2 Analysis of Physical Properties of Sand

5.2.1 Moisture release characteristics

5.2.1.1 Age and moisture release curves (MRC) in Shatin Turf Track

From water release curves of saturated sand cores, we can derived and study the volume and size distribution of pores in the track profile. The shape and slope of moisture release curve describes the speed of drainage. When looking at the curves from different sections of the Shatin turf track, data from the Stable Bend old section (SB), which is the oldest section, gives the flattest curve. This indicates that SB is very slow to drain and soil pores size is quite uniform. Although the total porosity is similar to other sections of the track, the amount of finer pores is high and the ability to hold water is significantly higher. The water holding characteristics is at the maximum acceptable level derived by Murphy and Field from TurfTech. At soil tension of 100 mb, soil water content remains high at 32%. This moisture level is a lot higher than the desirable level of around 25% moisture for racing. Thus the Stable Bend area will always be softer than other sections of the track and divot damage will be higher, with deeper and larger divots.

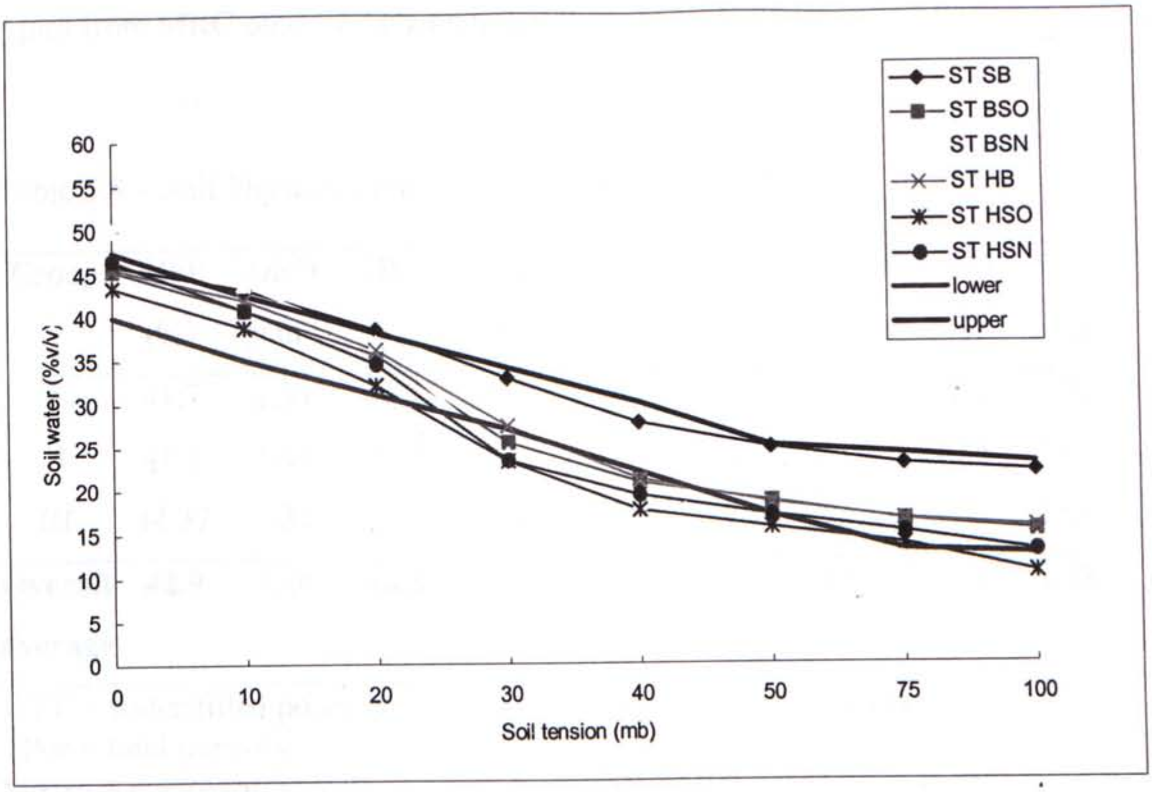


Figure 5.3 – Moisture Release Curve – Shatin Turf Track

Younger sections of the track, Home Straight New Section (HSN) and Back Straight New Section (BSN), have a quite different MRC. The drop of soil water content from 20mb to 40mb is very sharp, indicating that most of the water is drained from the pores at that tension. Moisture level then tapers off as the larger pores are drained and start to drain from smaller pores. It should be noted that the section of the curve 30-40 mb is below the minimum level of moisture and the profile is drier than optimum. At field capacity (35 mb or when track ceased to drain) profile moisture in HSN and BSN is close to 15-20% to maintain a desirable level of moisture for racing, pre-race irrigation is necessary.

Apart from MRC other soil characteristics are also studied:

Table 5.8 – Soil Physical Properties - Shatin

Group	WFP (%)	DBD (gcm^{-3})	TPor (%)	Voids (%)	Macro (%)	TAP (%)	PS100 (%)	PS35 (%)	Om (%)
I	41.7	1.39	47.2	5.5	23.9	32.3	32.0	49.5	4.90
II	41.3	1.41	46.7	4.1	27.8	34.7	25.7	40.5	3.95
III	44.37	1.33	48.3	5.9	32.2	39.8	17.3	31.5	2.57
Overall average	**42.9**	**1.40**	**46.8**	**3.9**	**29.0**	**36.3**	**22.7**	**38.1**	**3.42**

WFP = water filled porosity
DBD = dry bulk density
TPor = total porosity
Voids = air voids
Macro = macroporosity
TAP = total air-filled porosity
PS100 = pore saturation at 100mb
PS35 = pore saturation at 35mb
om = organic matter content

The range of DBD is quite narrow but the data are grouped into 1.40 g cm^{-3} for older sections and 1.30 g cm^{-3} for recently reconstructed sections. DBD for SB is lower than expected, this is because high organic matter content has diluted the density of sand profile. Newer section has lower DBD as they have experienced less usage and traffic, therefore is less compacted. But all samples have not exceeded the desirable range that would affect plant growth.

Total porosity across all ages is similar, it is very important to note that although the total amount of pores is similar, the properties of these pores changes. The amount of total air-filled pores and macroporosity, which is critical to fast drainage and gas exchange, decreases with age. Macropores will continually collapse as profile ages and shift from larger air-filled space to smaller water-filled pores. These will lead to higher profile moisture as shown in the gradual increase in pore saturation at 100mb and 35mb as profile ages.

A sharp increase in organic matter content is observed between sections build in 1989/90 and the sections reconstructed in 1996/97/98. The build up of organic matter could relieve the effect of profile compaction but it could also clog up larger drainage pores and slow down drainage significantly.

5.2.1.2 MRC and profile design in Happy Valley Old and New Sections

Profile age and design of Happy Valley track is relatively uniform as the track was reconstructed in 1995 except for the small trial sections at Home and Back Straight, which was built again in 1997 based on the new StrathAyr design.

As in Shatin, the older profile gives a flatter MRC indicating slower drainage and uniform distribution of pore size. At tension 10-20mb, that is near saturation, moisture content of older profile is slightly above the desirable range which indicate that initial drainage rates are lower than optimum. New StrathAyr system also generates high surface moisture at near saturation. However, as it begins to drain from 10-30 mb, soil water drops dramatically to levels below desirable minimum. As the MRC tapers off at field capacity, soil water level is also lower than desirable which shows that the profile could be constantly drier than desirable. Soil water at field capacity is around 15%, much lower than the optimum 20% moisture for racing. To compensate for the quick loss of moisture, these new areas need additional watering to produce a desirable racing surface.

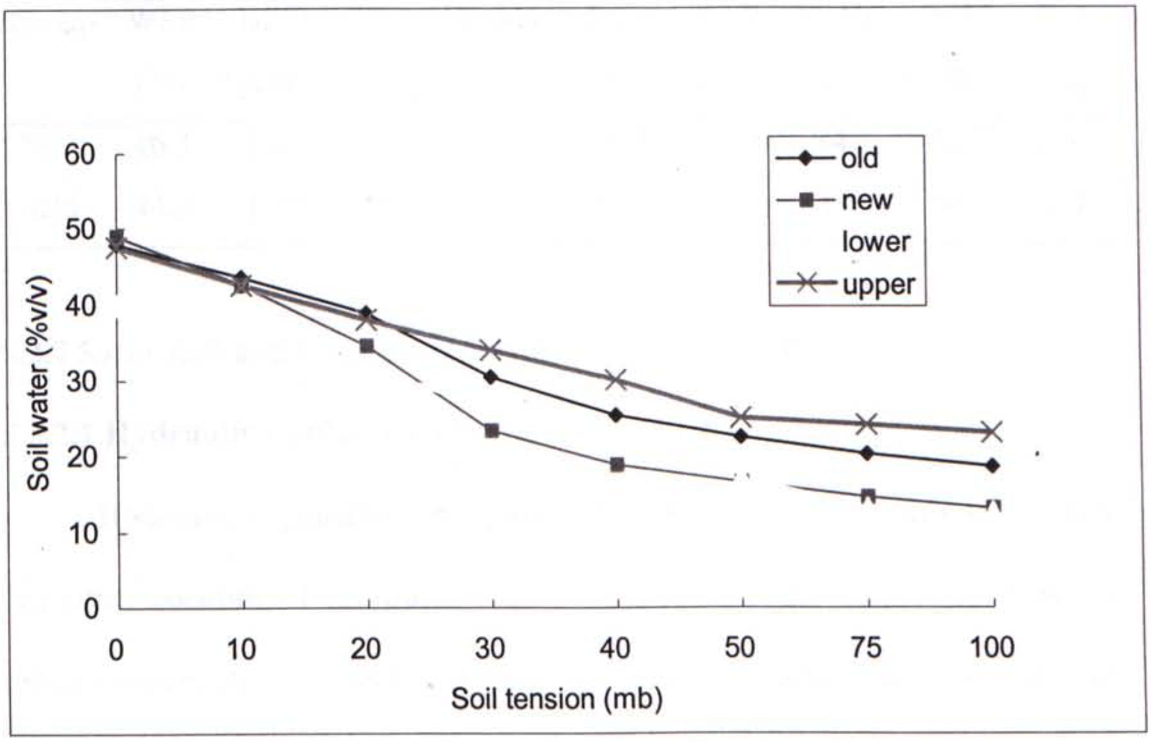


Figure 5.4 – Moisture Release Curve – Happy Valley Old VS New Sections

Dry bulk density of new areas is about 8% lower than other sections and the average density of 1.26 g cm^{-3} is very low. Macroporosity is about 20% higher and Total air-filled pore is 17% higher than old sections. High macroporosity indicates that the profile will dry up very quickly once drainage begins. These factors together with low soil water at field capacity (15% soil water) creates a profile that is very sensitive to changes in water content and when not compacted by heavy roller to increase bulk density the surface would be unstable and difficult to hold together. The management window to create an optimum racing service is narrow.

Table 5.9 – Soil Physical Properties – Happy Valley

Group	WFP (%)	DBD (gcm^{-3})	TPor (%)	Voids (%)	Macro (%)	TAP (%)	PS100 (%)	PS35 (%)	Om (%)
New	46.3	1.26	50.4	4.2	33.4	41.25	14.8	48.3	2.55
Old	44.3	1.36	48.4	4.1	27.8	35.3	21.0	54.9	3.4

5.2.2 Saturated and unsaturated hydraulic conductivity

5.2.2.1 Hydraulic conductivity in Shatin

Hydraulic conductivity of Shatin Stable Bend is significantly lower than any other sections of the track. This correlates with the data from moisture release curve. At saturation and near saturation condition, drainage of soil water depends heavily on large pore space. High bulk density reduces pore space, high organic matter content could block off drainage pathways together with low macroporosity significantly limits drainage rates at saturation. These will create a profile that is too slow to drain and profile will remain too moist.

Stable Bend being the oldest section has the lowest hydraulic conductivity. The second group (BSO & HSO) has higher conductivity, above 100 mm hr^{-1}, which is sufficient to handle usual torrential rainfall. The third group (HB, HSN & BSN) that was recently reconstructed has much higher conductivity as macroporosity is higher, bulk density and organic matter content is lower to facilitate drainage.

Table 5.10 - Hydraulic conductivity in Shatin

Group	Saturated (mm hr^{-1})	2 mb (mm hr^{-1})	4 mb (mm hr^{-1})	10 mb (mm hr^{-1})
I	50	40	40	20
II	175	90	88	73
III	383	107	91	80
Overall Avg	**258**	**90**	**82**	**68**

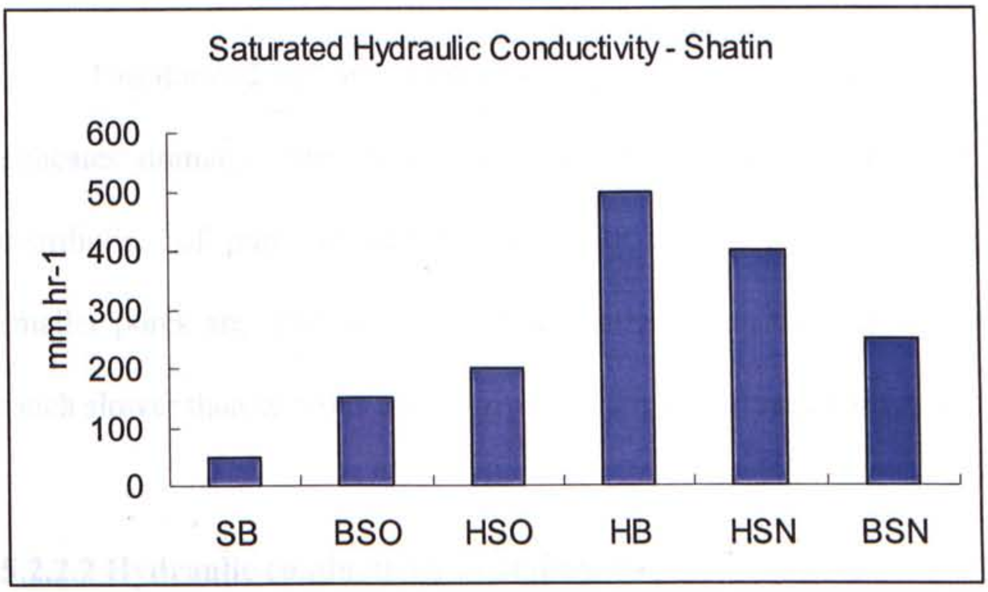


Figure 5.5 – Saturated Hydraulic Conductivity – Shatin

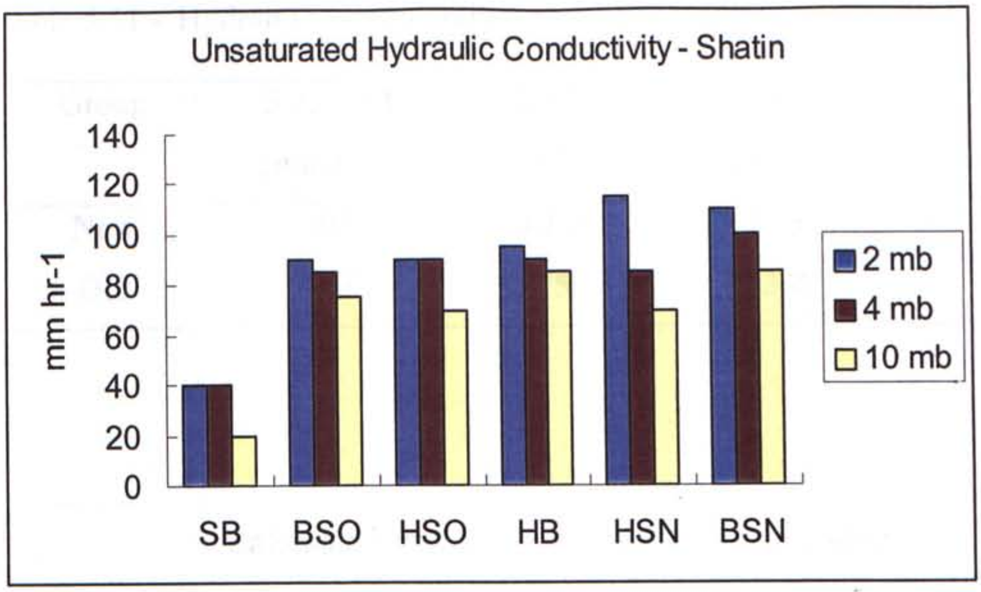


Figure 5.6 – Unsaturated Hydraulic Conductivity – Shatin

Unsaturated hydraulic conductivity at different soil tension (2, 4, 10mb) indicates drainage rates right after raining has ceased and could illustrate distribution of pores of different size. As tension increases, progressively smaller pores are drained. As with saturation rates, the Stable Bend area is much slower than sections and newly reconstructed areas drains at faster rates.

5.2.2.2 Hydraulic conductivity in Happy Valley

Saturated hydraulic conductivity is very uniform among various sections. The two new sections only drain slightly faster than the 1995 areas. The different depths of construction sand affected mostly the water holding properties of the profile but have little effect on drainage rates.

Table 5.11 – Hydraulic Conductivities in Happy Valley

Group	Saturated (mm hr^{-1})	2 mb (mm hr^{-1})	4 mb (mm hr^{-1})	10 mb (mm hr^{-1})
New	**105**	**82.5**	**77.5**	**70**
Old	**97.5**	**75**	**73.8**	**65**

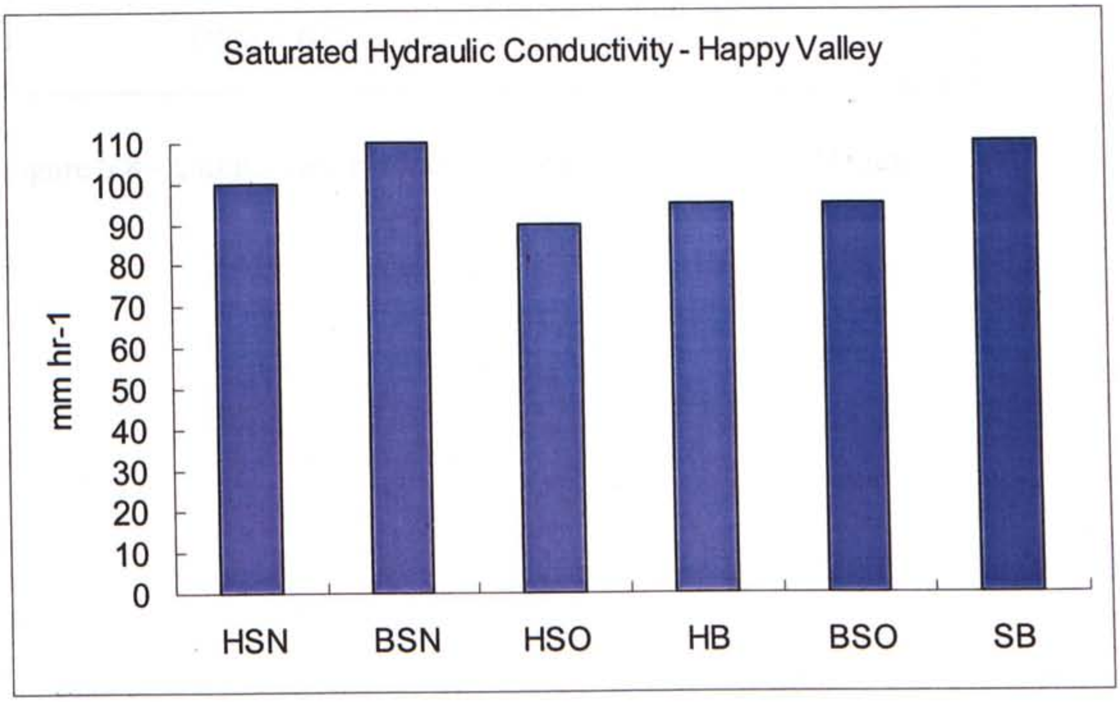


Figure 5.7 – Saturated Hydraulic Conductivity – Happy Valley

It should noted that in older sections, conductivity at 2mb and 4mb is the same, indicating that pore size are uniform and there is no increase in pore space as tension increases. On the contrary, the distribution of pore size in the new areas is more spread out with large and small pores, hence variation in conductivities is observed across different tensions.

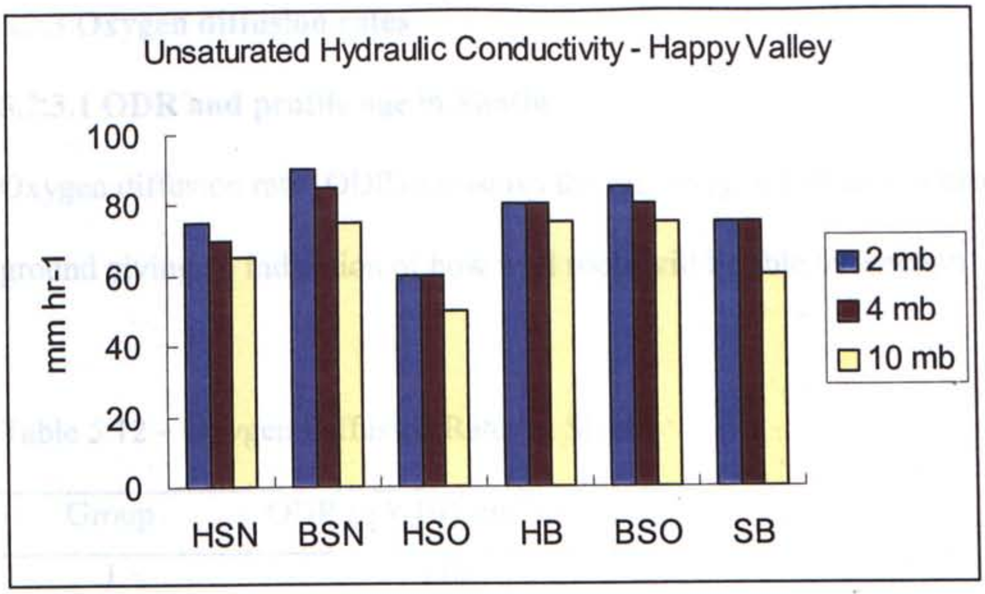


Figure 5.8 - Unsaturated Hydraulic Conductivity – Happy Valley

5.2.3 Oxygen diffusion rates

5.2.3.1 ODR and profile age in Shatin

Oxygen diffusion rate (ODR) measures the rate oxygen moves to a probe in the ground giving an indication of how well roots will be able to function.

Table 5.12 – Oxygen Diffusion Rates in Shatin

Group	ODR (g x 10^{-8} $cm^{-2}min^{-1}$)
I	110
II	145
III	167
Overall Avg	**150**

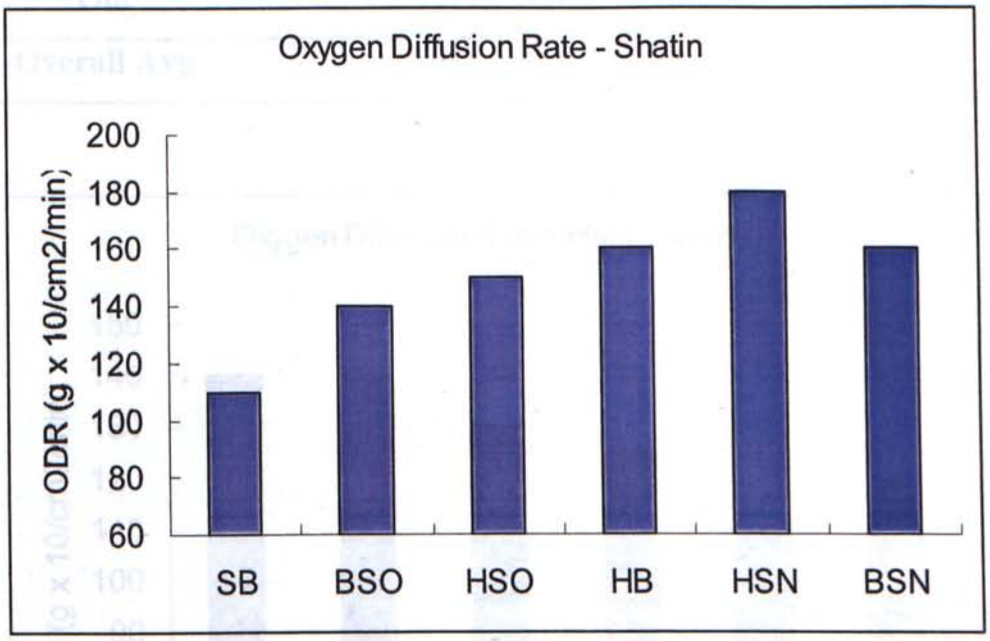


Figure 5.9 – Oxygen Diffusion Rate in Shatin

All ODR taken from Shatin turf track is within the desirable range of 100-150 g x 10^{-8} $cm^{-2}min^{-1}$. In compliance with other soil physical data, ODR is lowest in Stable Bend area (50% lower than new profiles) and the reconstructed areas have highest rates (15% higher than Group II and 50% higher than Group I).

5.2.3.2 ODR and profile design in Happy Valley

As expected ODR in Happy Valley new sections are about 15% higher than old sections. This is evident as the new areas has much higher macropores and total air-filled porosity, thus ODR should be higher. Variations within group is relatively small

Table 5.13 – Oxygen Diffusion Rates in Happy Valley

Group	ODR (g x 10^{-8} $cm^{-2}min^{-1}$)
New	140
Old	121
Overall Avg	**106**

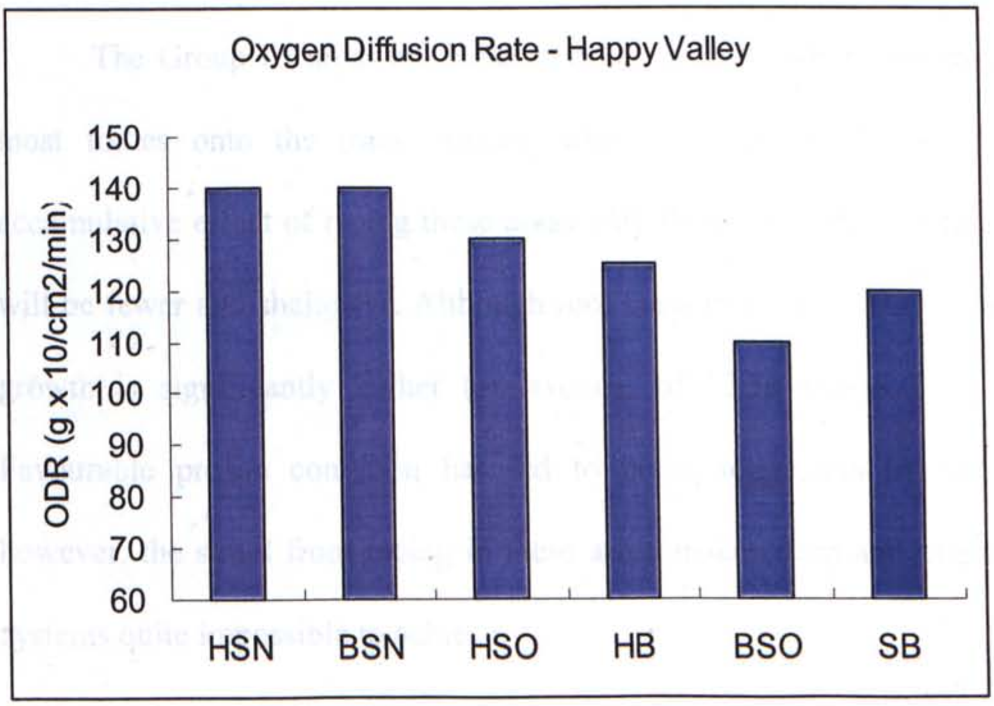


Figure 5.10 – Oxygen Diffusion Rates in Happy Valley

5.2.4 Grass biomass

5.2.4.1 Biomass and variation in profile age in Shatin

Contrary to expectations, the amount of live roots is actually higher in the older sections of the track (Group I and II). Apart from consideration of the profile physical condition, the racing pattern also has a strong influence and root growth.

Table 5.14 – Biomass in Shatin

Group	Live roots ($kg\ m^{-2}$)	Stolon ($kg\ m^{-2}$)
I	5.4	4.7
II	4.2	2.5
III	2.1	12.3
Overall Avg	**3.35**	**7.78**

The Group III areas are close to or at the bend where horses exert the most forces onto the track creating more and deeper divots. Under the accumulative effect of racing these areas will always be catching up and roots will be fewer and shallower. Although root mass is lower in new areas, stolon growth is significantly higher (an average of 12.33 versus 3.23 kg m^{-3}). Favourable profile condition has led to better topgrowth of turf grasses, however, the stress from racing in these areas makes deep and extensive root systems quite impossible to achieve.

5.2.4.2 Biomass and variation in profile design in Happy Valley

When comparing biomasses between old and new sections, the new areas are much inferior to the older areas in terms of root and top growth. The amount of live roots is only 47% and stolon mass is 60% of the old areas.

Table 5.15 – Biomass in Happy Valley

Group	Live roots ($kg\ m^{-2}$)	Stolon ($kg\ m^{-2}$)
New	1.3	4.7
Old	2.73	7.7
Overall Avg	**2.25**	**6.7**

.These new areas remains too moist on the surface and too dry in the subsurface which encourage shallow rooting and become unstable to race on. As a result grass growth is inferior and track surface became substandard for racing

5.2.4.3 Biomass and the effect of shade in Happy Valley

When investigating soil physical properties, little variance was observed between the full-sun area and the shaded area. However, a marked difference is observed in turfgrass biomasses. The shaded areas produce 35% less live and 45% less stolons than grasses receiving full sunlight. The differences in the amount of light hours received have proved to be very difficult to turf management. For vigorous Tifton growth full sunlight is essential, to compensate for the lack of direct sunlight, light truss with greenhouse lighting has been used. Owing to the size of the track, such setup proves to be insufficient to produce meaningful results. As a result, grass growth along the home straight will always be inferior to the back straight, with slower recovery rate, more rye grass growth and more difficult in the transition from a rye grass track to Tifton track.

Table 5.16 – Biomass in Happy Valley (Shade Effect)

	Live roots (kg m^{-2})	Stolon (kg m^{-2})
Shade	**1.75**	**4.3**
Full sun	**2.73**	**7.9**

5.2.5 Track hardness

5.2.5.1 Track hardness and variation in profile age in Shatin

As expected from soil physical properties of high organic matter, low dry bulk density and high moisture at field capacity, the Stable Bend area is significantly softer than other newer sections of the track.

Table 5.17 Track Hardness Values in Shatin

Group	Penetrometer reading	Clegg hammer reading
I	2.85	60
II	2.67	68
III	2.55	72
Overall Avg	**2.64**	**68.7**

Differences between Group II and III areas are less distinct. Data from penetrometer and Clegg hammer correlates well and both could detect changes in profile hardness.

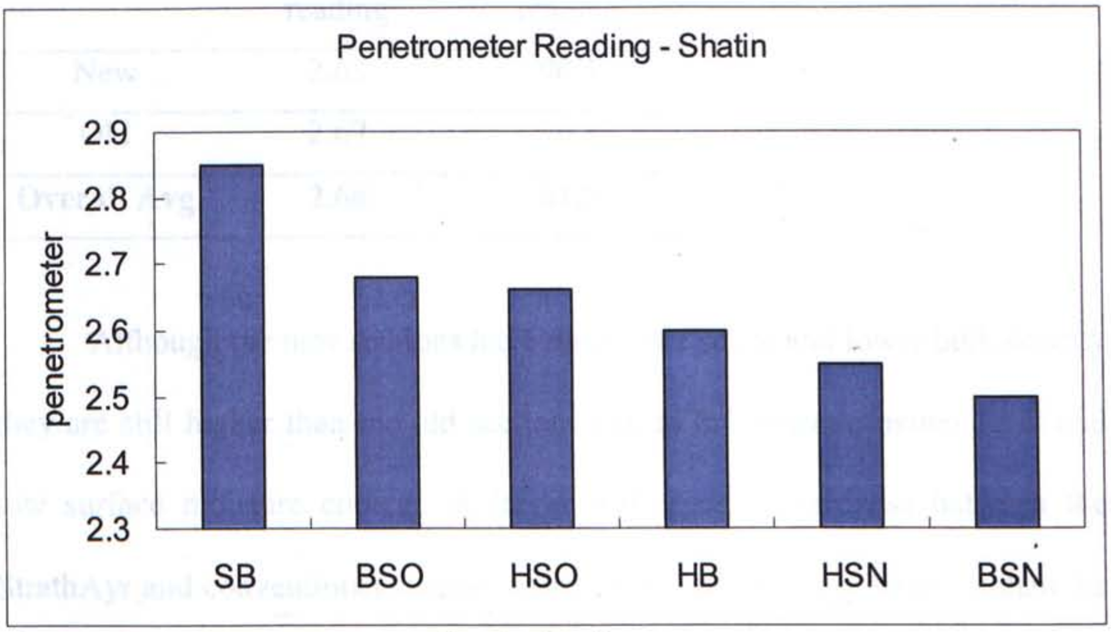


Figure 5.11 – Penetrometer reading in Shatin

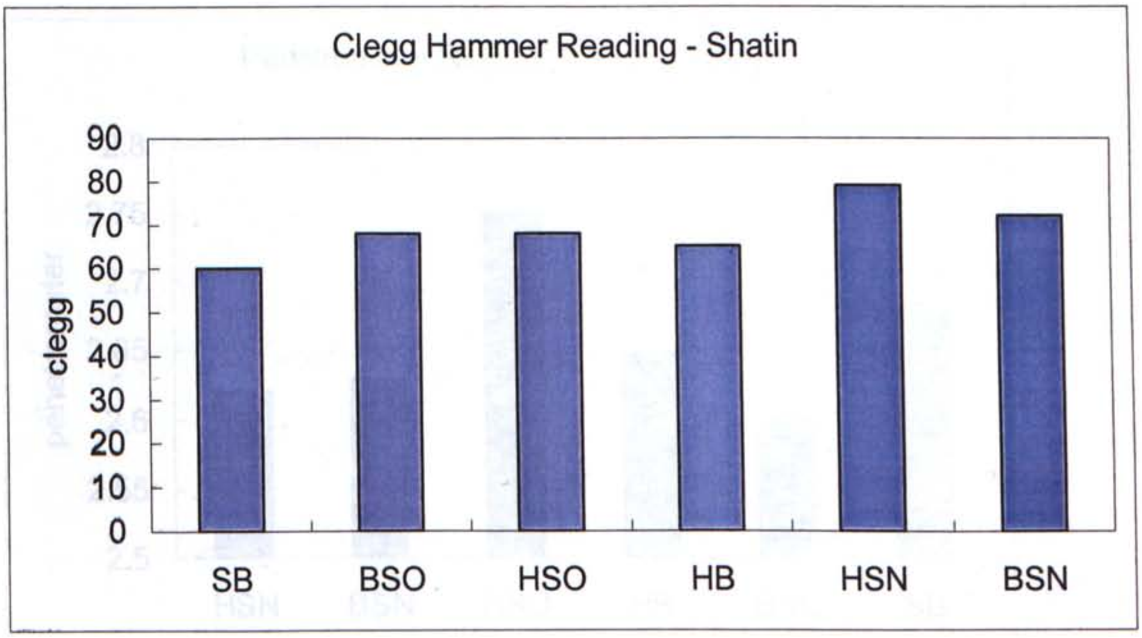


Figure 5.12 – Clegg Hammer Reading in Shatin

5.2.5.2 Track Hardness and variation in profile design in Happy Valley

Table 5.18 – Track Hardness Values in Happy Valley

Group	Penetrometer reading	Clegg hammer reading
New	2.63	90.5
Old	2.67	76.8
Overall Avg	**2.66**	**81.3**

Although the new sections have more pore space and lower bulk density, they are still higher than the old sections due to low organic matter level and low surface moisture content. A larger difference in hardness between the StrathAyr and conventional section is picked up by the Clegg hammer than the penetrometer. An 18% difference is spotted by the Clegg hammer but a mere 2% was picked up by the penetrometer.

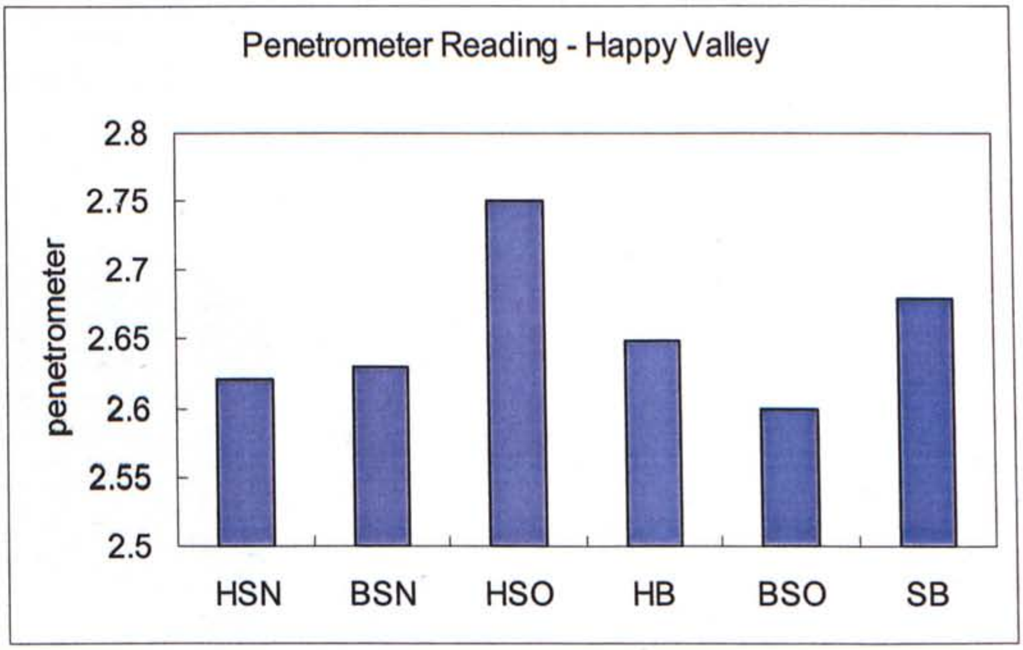


Figure 5.13 – Penetrometer Reading in Happy Valley

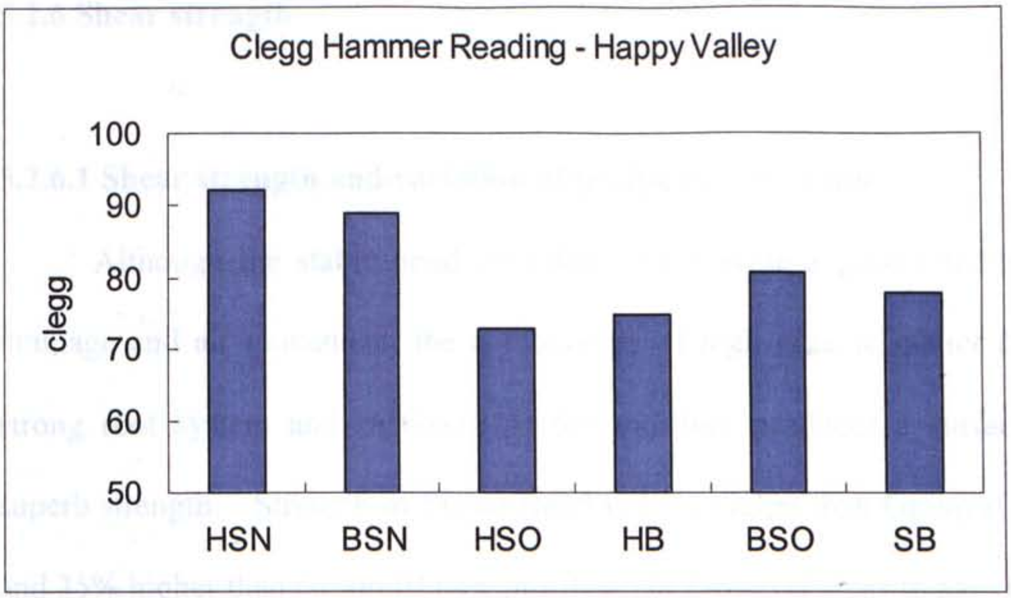


Figure 5.14 – Clegg Hammer Reading in Happy Valley

5.2.6 Shear strength

5.2.6.1 Shear strength and variation of profile age in Shatin

Although the stable bend area does not provide a good condition for drainage and air movement, the combination of high organic matter content, strong root system and sufficient profile moisture produces a surface with superb strength. Strength of Stable Bend is 18% higher than Group II profile and 35% higher than Group III new profiles. The Group II areas remain to be in the middle, whereas the newer areas have inferior strength.

Table 5.19 – Shear Strength Value in Shatin

Group	Shear strength (kPa)
I	80
II	68
III	59.3
Overall Avg	**65.7**

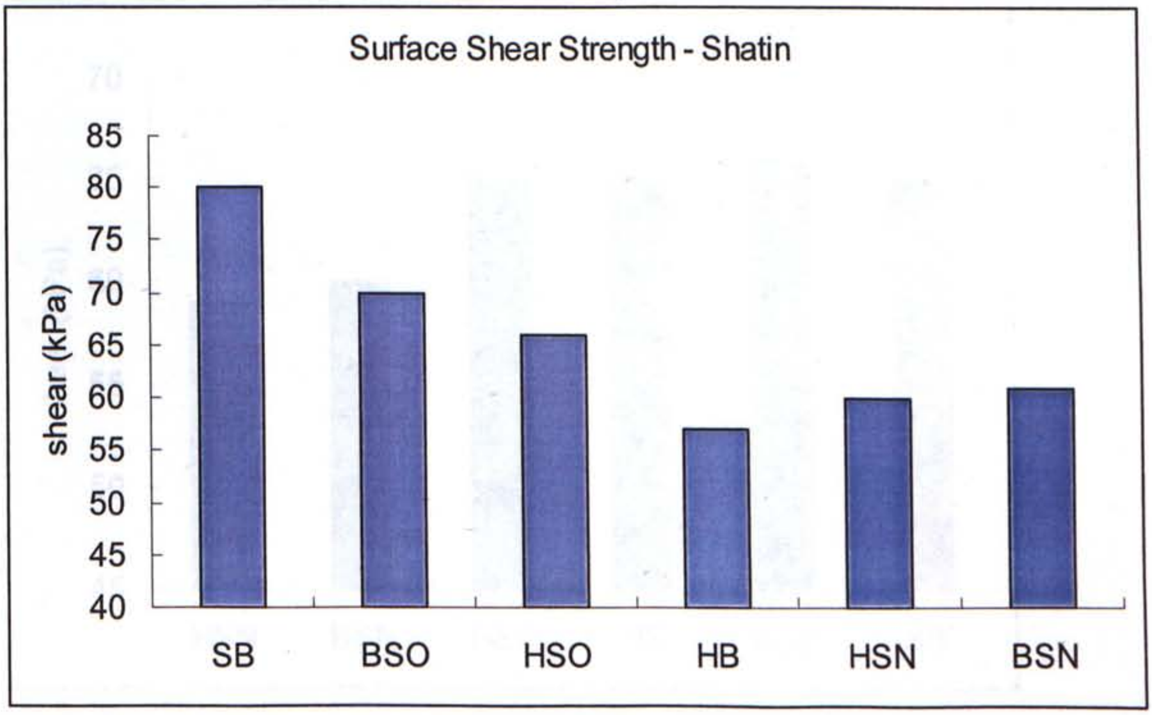


Figure 5.15 – Surface Shear Strength in Shatin

5.2.6.2 Track hardness and variation in profile design in Happy Valley

Table 5.20 – Shear Strength Value in Happy Valley

	Shear Strength (kPa)
New	59.5
Old	65.3
Overall avg	**63.3**

As expected from other properties of these profiles, such as high porosity, low bulk density and poorer root growth, the new sections are unlikely to hold on together. Thus, the Happy Valley new profile is about 10% weaker in shear strength than the older section. It should be noted that the shear strength properties among the other old sections is very uniform.

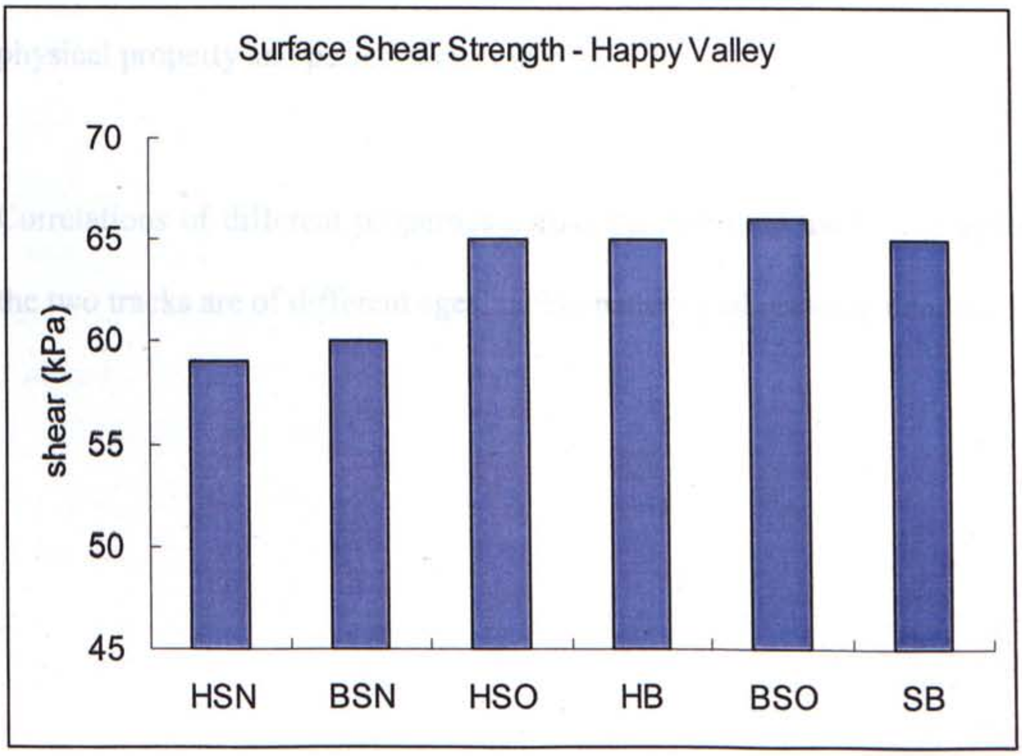


Figure 5.16 – Surface Shear Strength in Happy Valley

5.3 Correlation between soil physical properties and performance index

5.3.1 Correlation between soil physical properties and shear strength value

Table 5.21 - Correlation with Profile Shear Strength (r^2 value $p <= 0.05$)

R^2 value	Shatin	Happy Valley
Dry bulk density	* 0.199	0.942
Total porosity	* 0.081	* 0.170
Macroporosity	0.865	0.937
Organic matter content	0.960	0.880
Saturated hydraulic conductivty	0.973	* 0.313
Unsaturated hydraulic conductivity	0.795	* 0.069
Oxygen diffusion rate	0.901	0.940
Root mass	0.802	0.980
Stolon mass	*0.533	*0.563

R^2 value with '*' indicates insignificant correlation between that particular soil physical property and performance index

Correlations of different properties across the two race tracks are different as the two tracks are of different ages, racing pattern and growing condition.

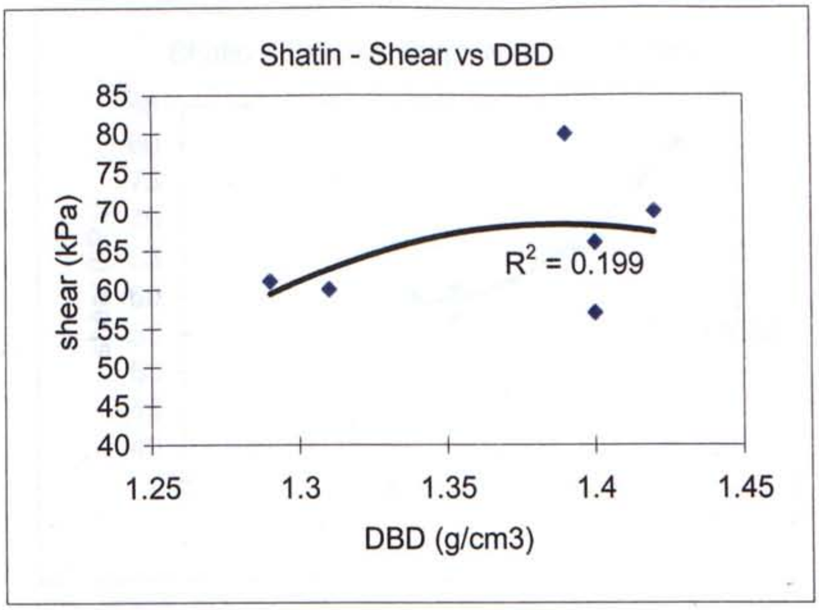
5.3.2 Correlation between soil physical properties and surface hardness

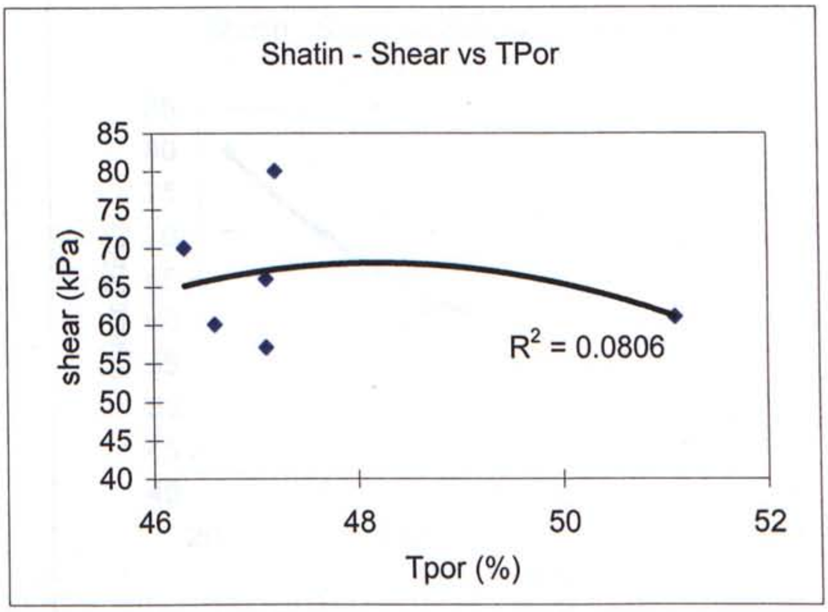
Table 5.22- Correlation with Profile Hardness – Clegg hammer readings (r^2, $p<=0.05$)

	Shatin	Happy Valley
Dry bulk density	*0.518	0.796
Total porosity	*0.337	*0.222
Macroporosity	0.743	0.777
Organic matter content	0.591	0.821
Saturated hydraulic conductivty	0.732	0.555
Unsaturated hydraulic conductivity	0.880	*0.270
Oxygen diffusion rate	0.794	0.878
Root mass	0.416	0.976
Stolon mass	*0.956	*0.332

Table 5.23 - Correlation with Profile Hardness – Penetrometer readings (r^2, $p<=0.05$)

	Shatin	Happy Valley
Dry bulk density	*0.573	0.878
Total porosity	*0.388	0.816
Macroporosity	0.959	*0.176
Organic matter content	0.933	0.562
Saturated hydraulic conductivty	0.908	0.740
Unsaturated hydraulic conductivity	0.937	0.814
Oxygen diffusion rate	0.878	*0.620
Root mass	0.626	0.718
Stolon mass	0.611	*0.292





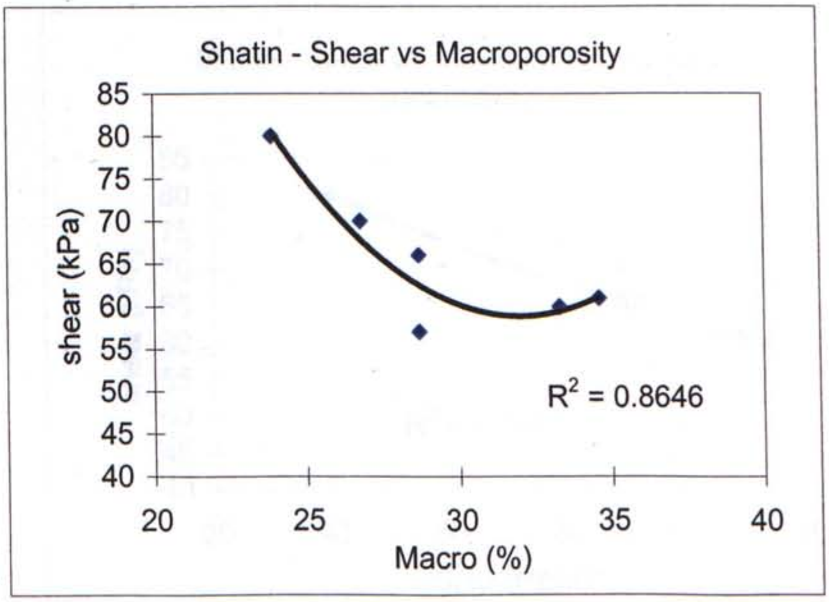
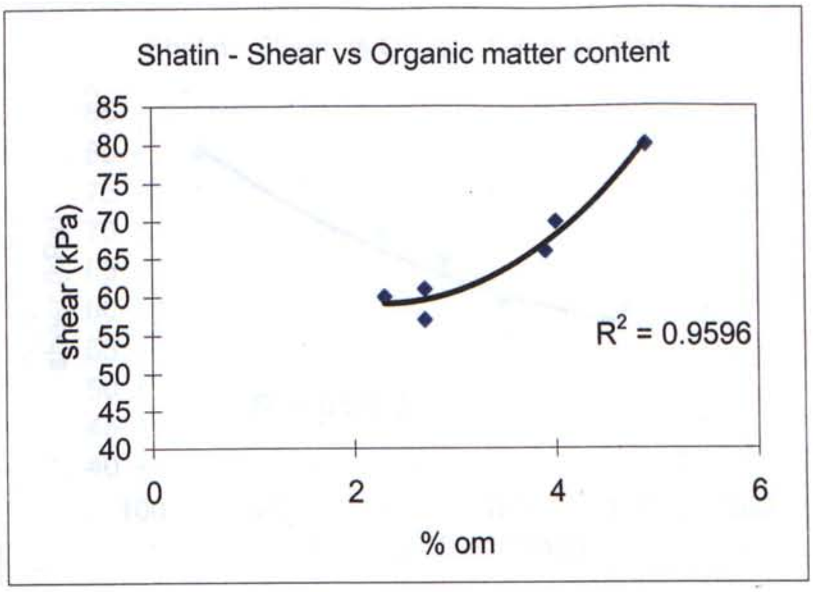
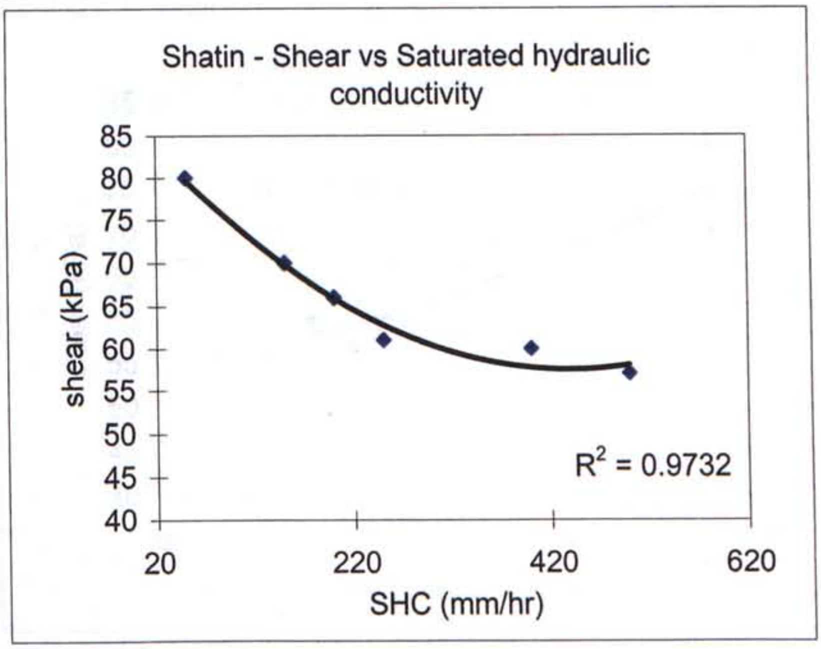


Figure 5.17 - Correlation of soil physical properties with shear strength in Shatin





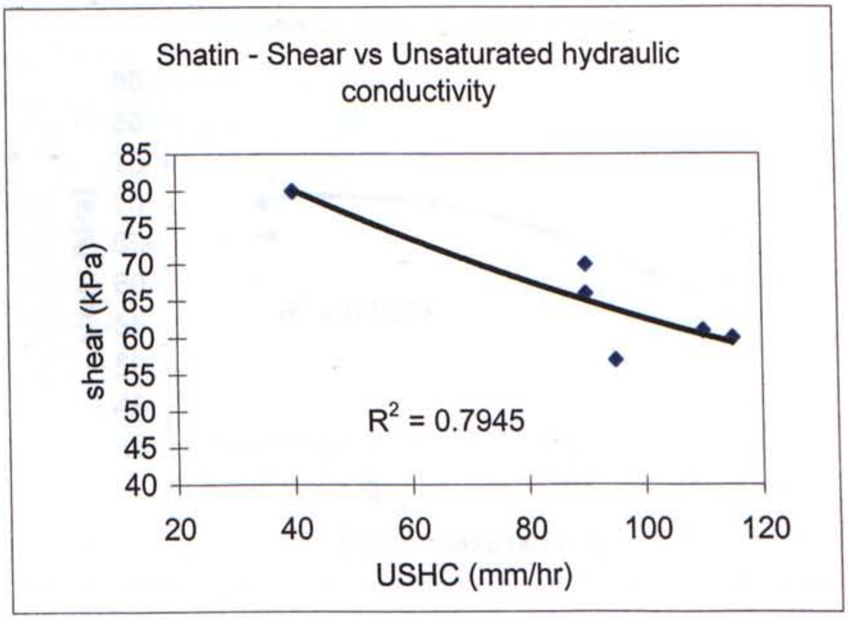
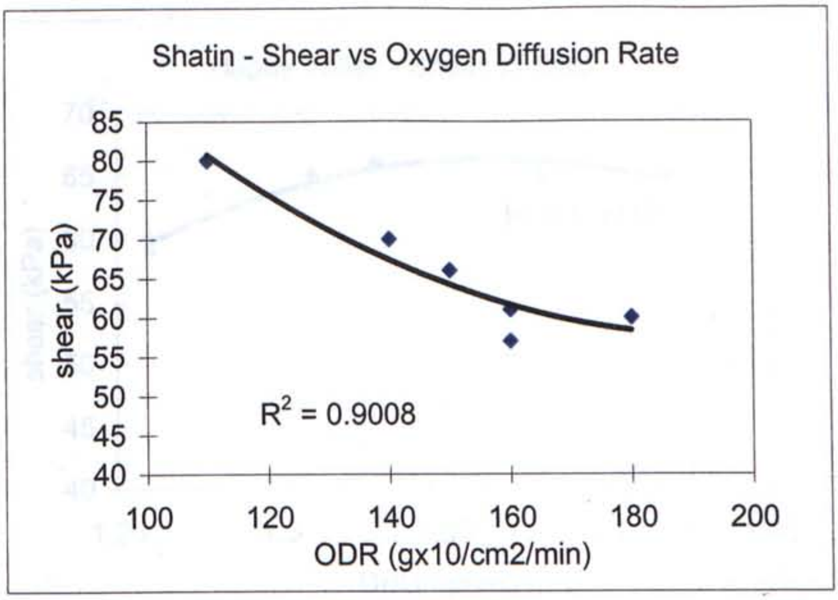
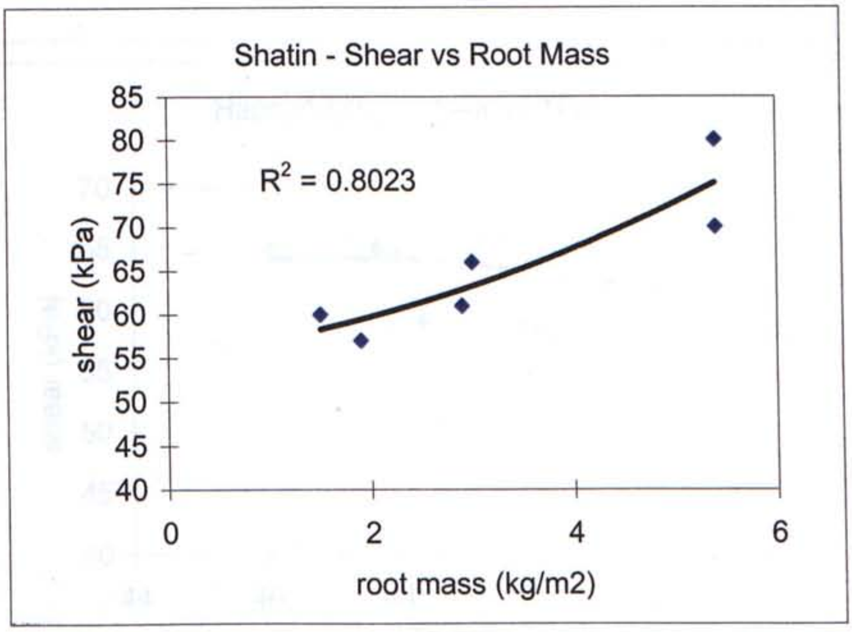


Figure 5.17 - Correlation of soil physical properties with shear strength in Shatin





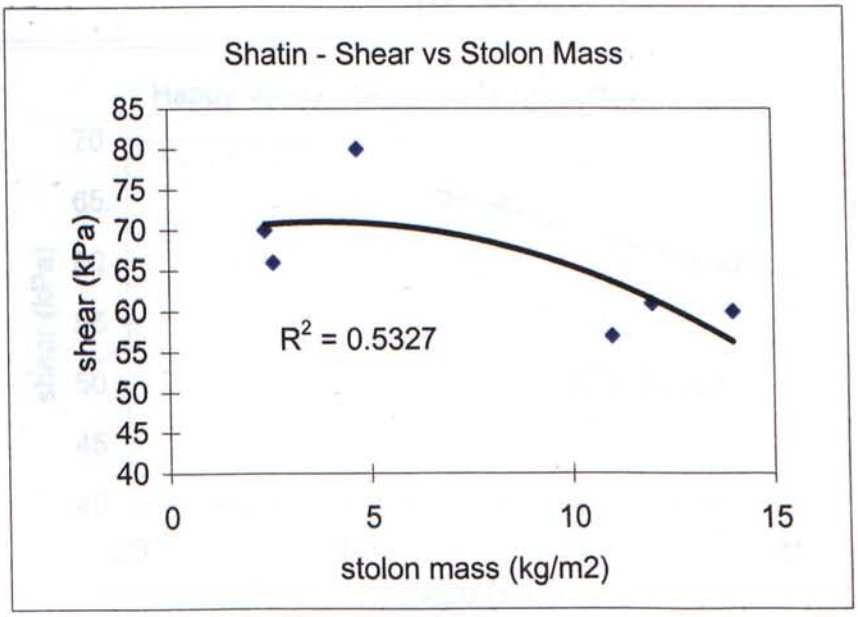


Figure 5.17 - Correlation of soil physical properties with shear strength in Shatin

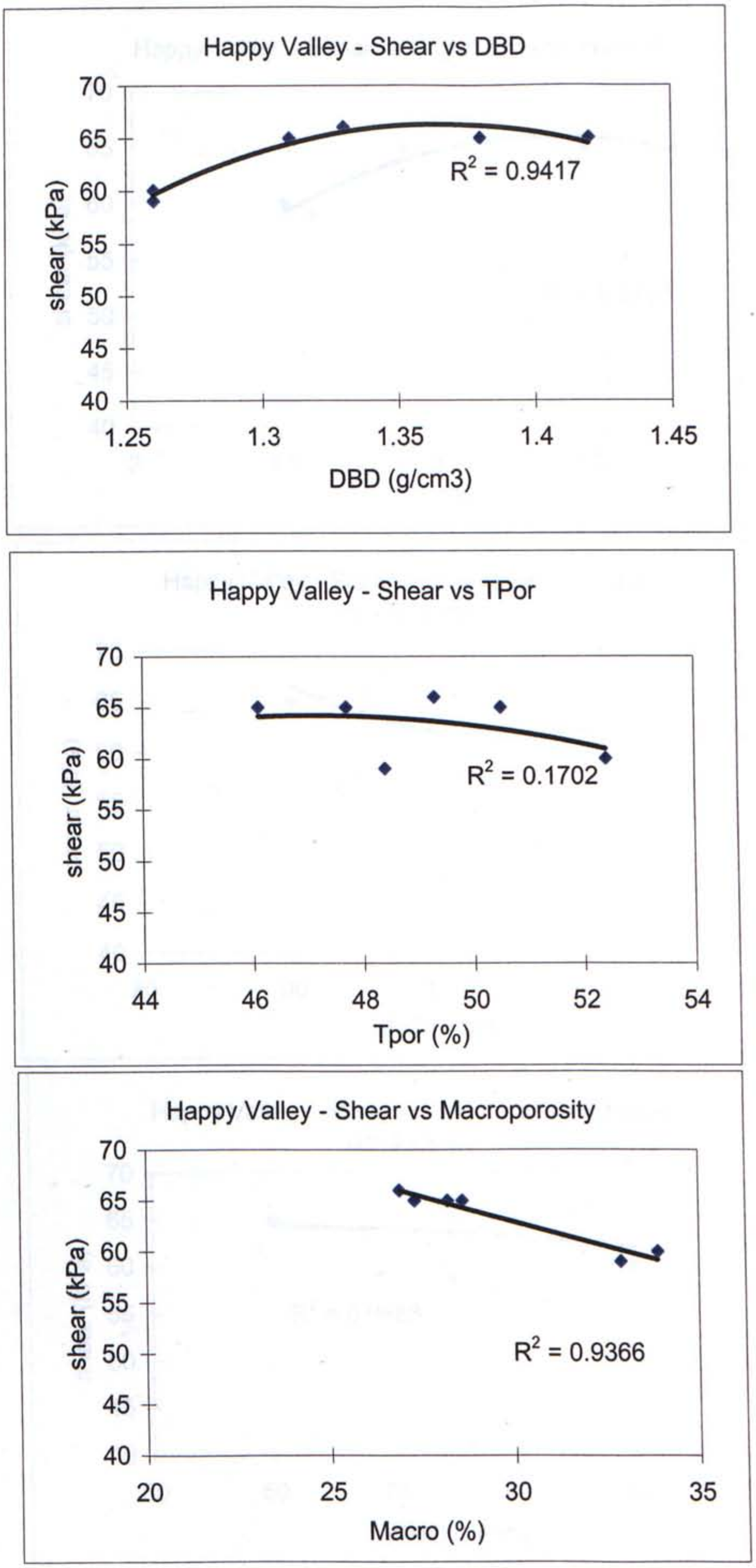


Figure 5.18 - Correlation of soil physical properties with shear strength in Happy Valley

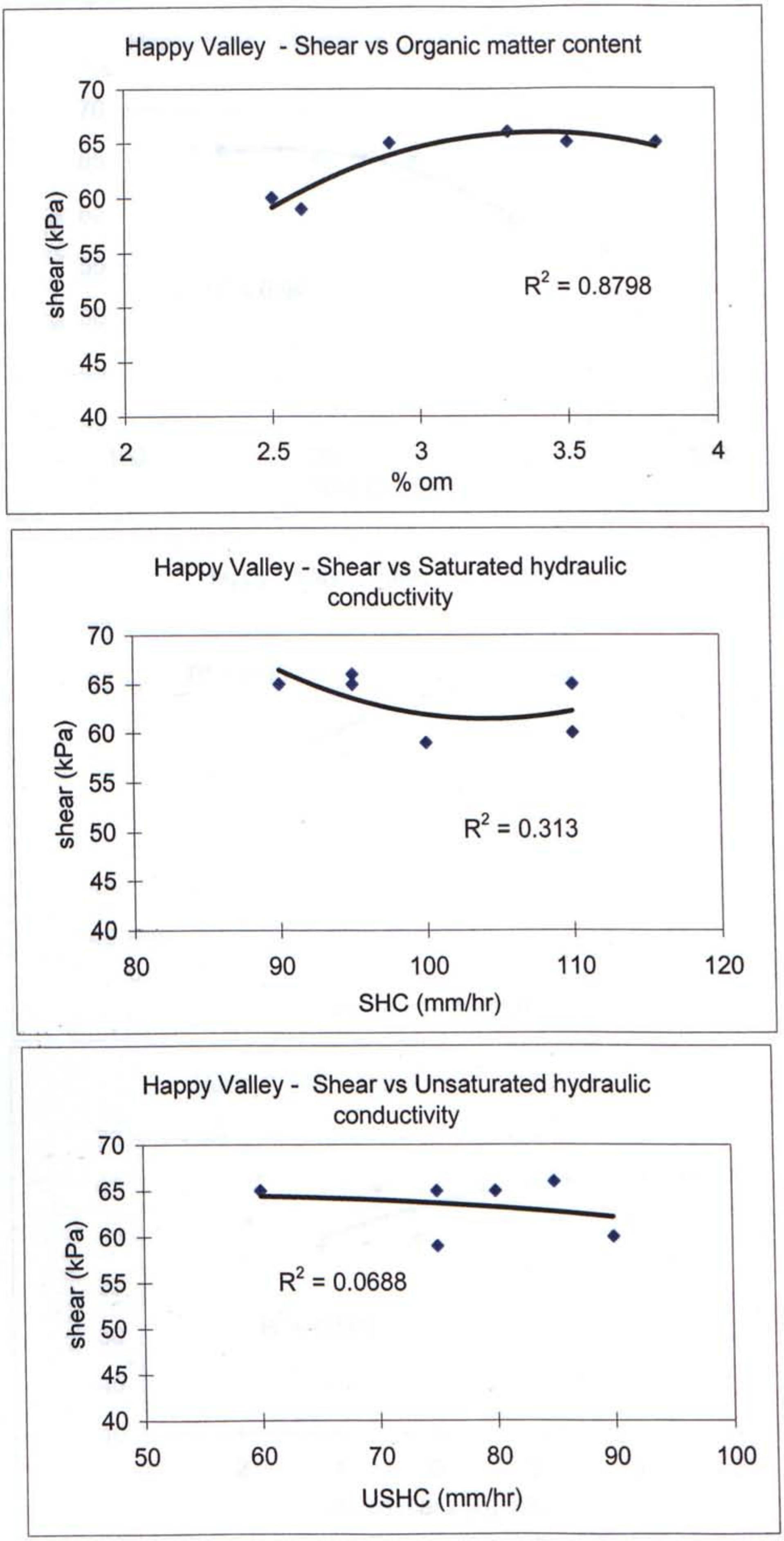


Figure 5.18 - Correlation of soil physical properties with shear strength in Happy Valley

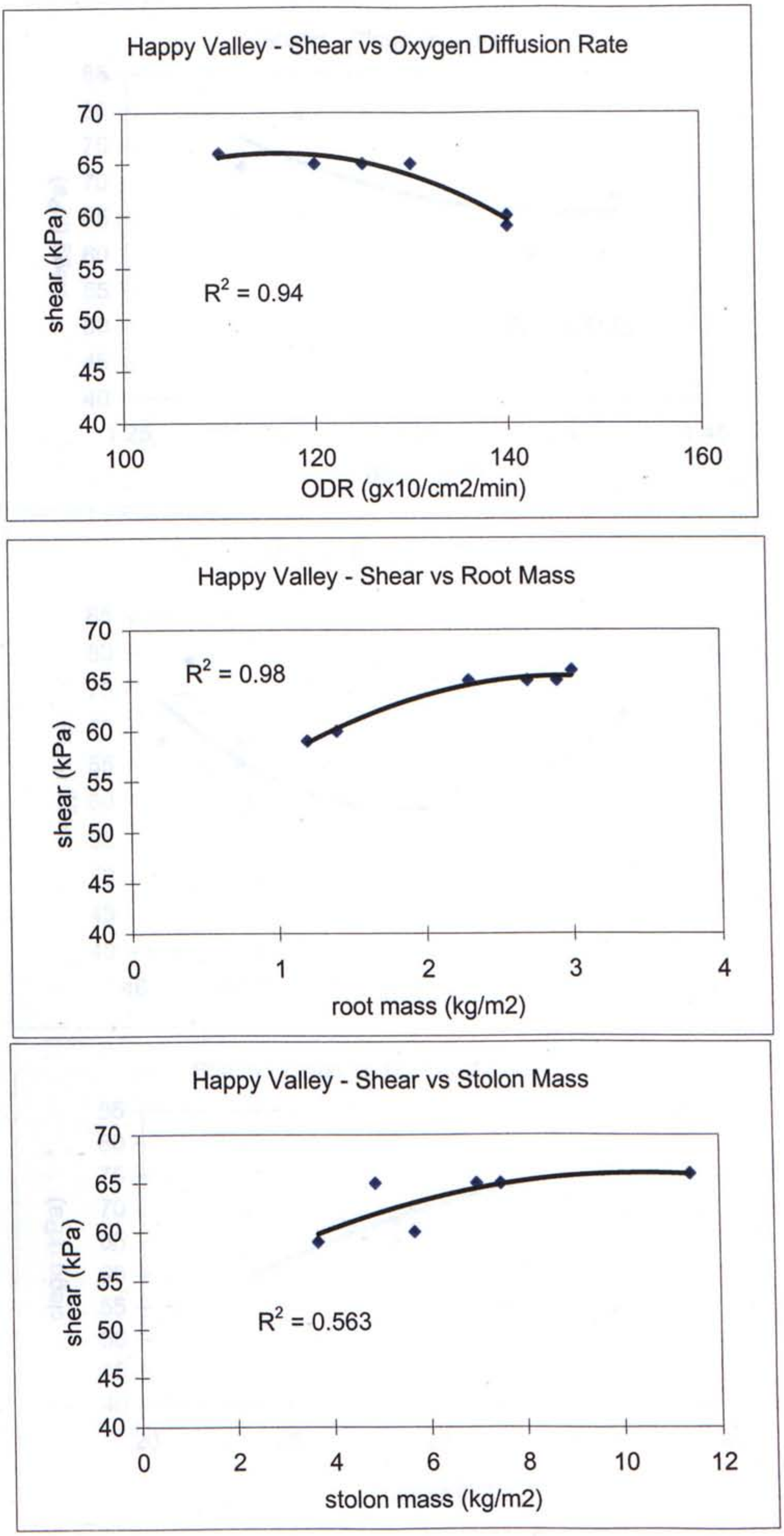
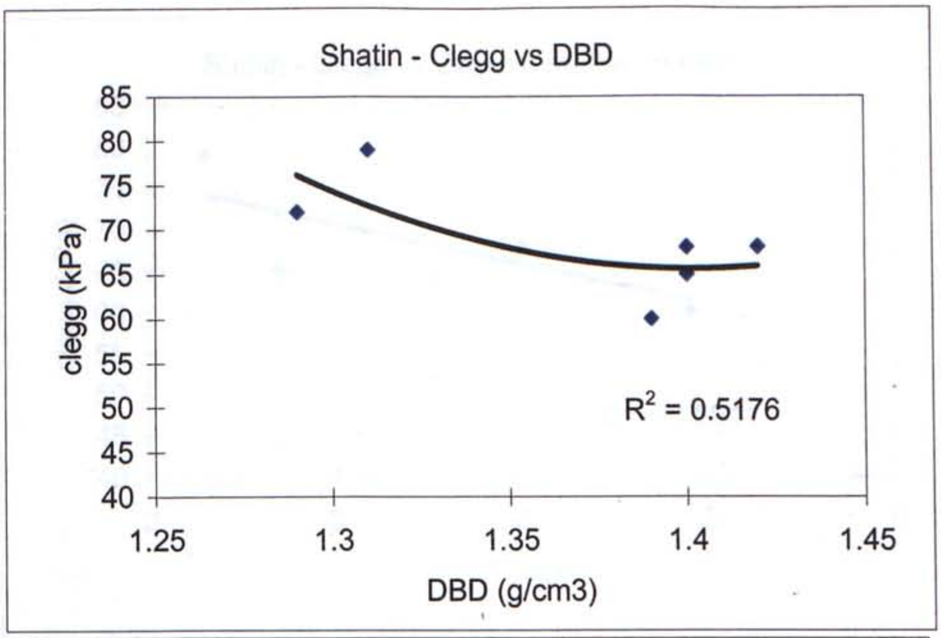
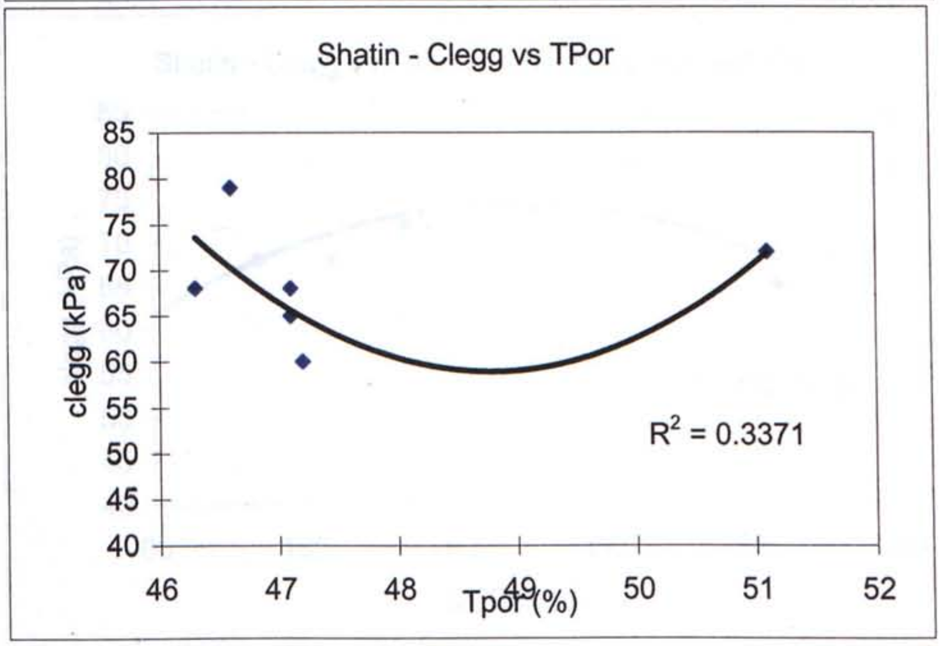


Figure 5.18 - Correlation of soil physical properties with shear strength in Happy Valley





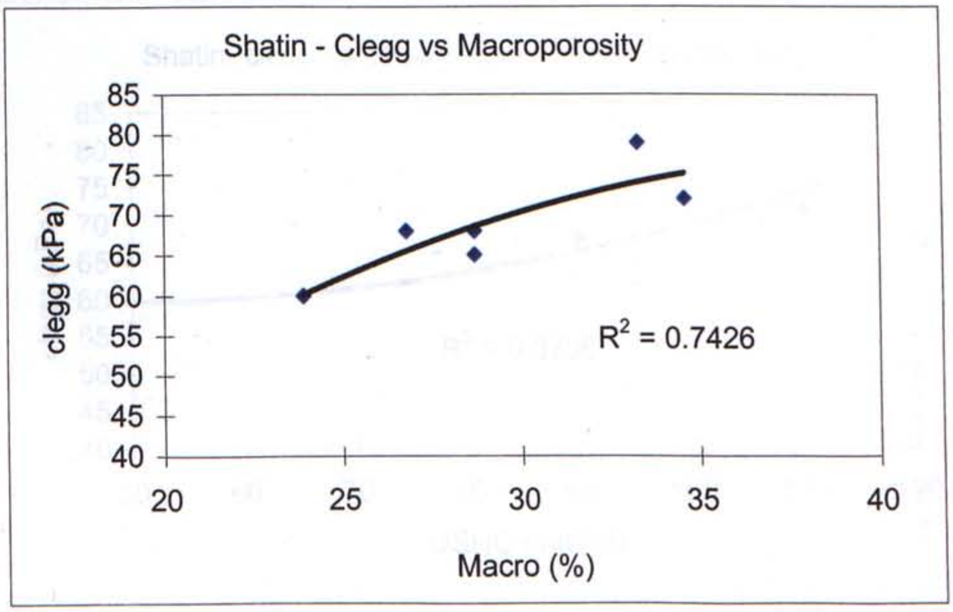
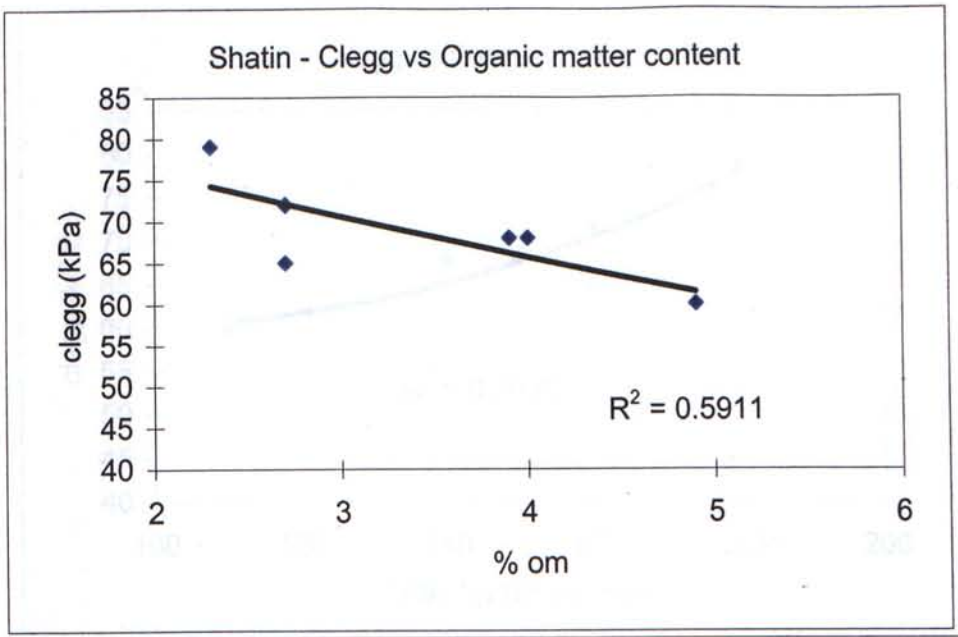
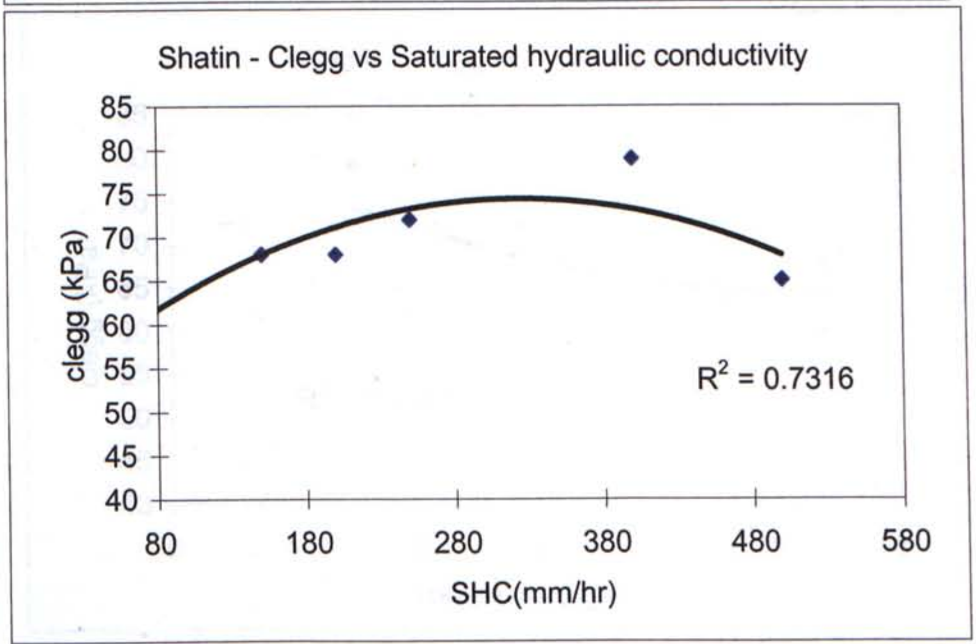


Figure 5.19 - Correlation of soil physical properties with clegg hammer values in Shatin





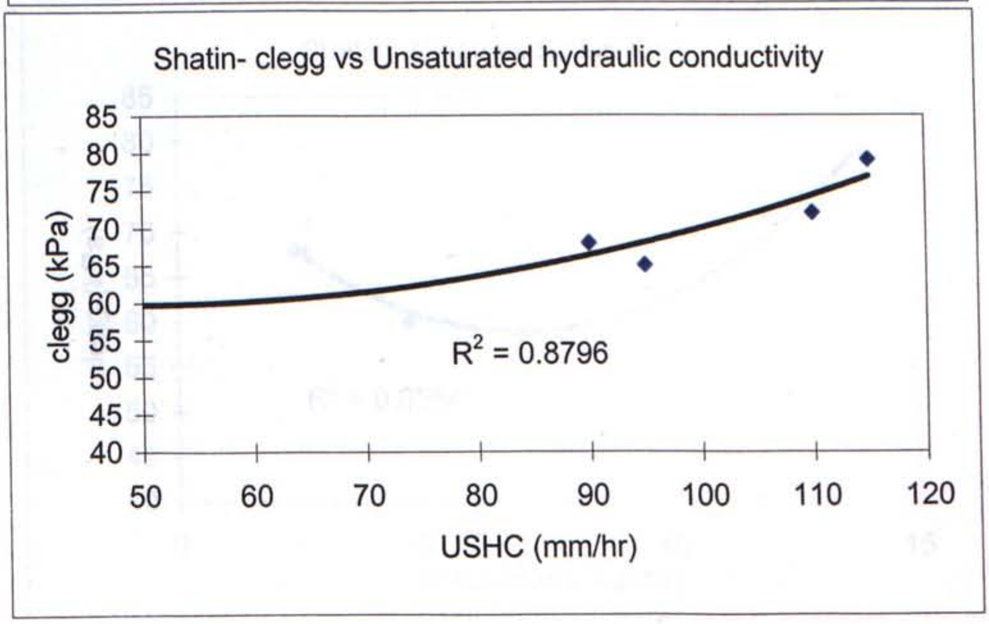


Figure 5.19 - Correlation of soil physical properties with clegg hammer values in Shatin

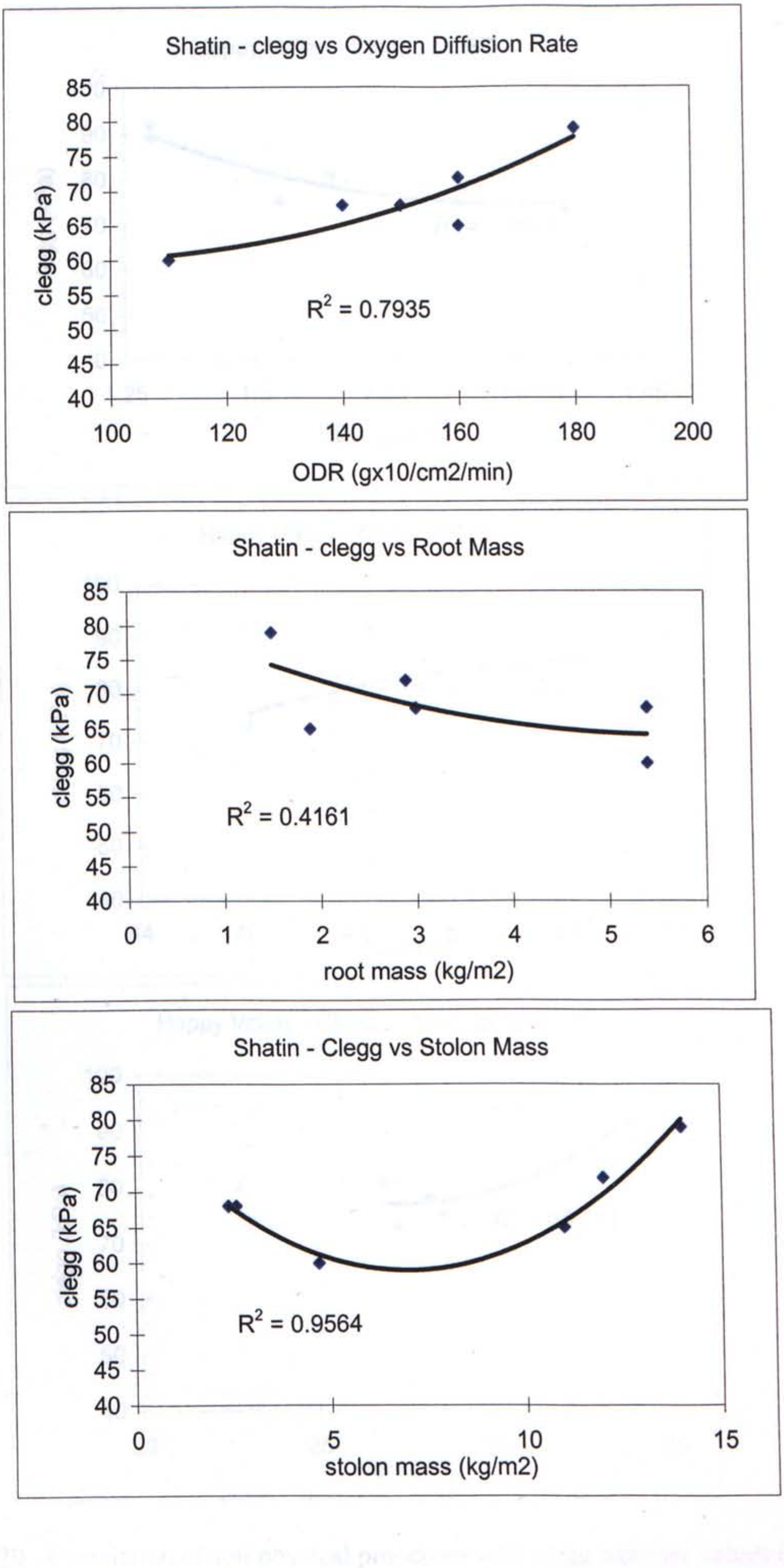


Figure 5.19 - Correlation of soil physical properties with clegg hammer values in Shatin

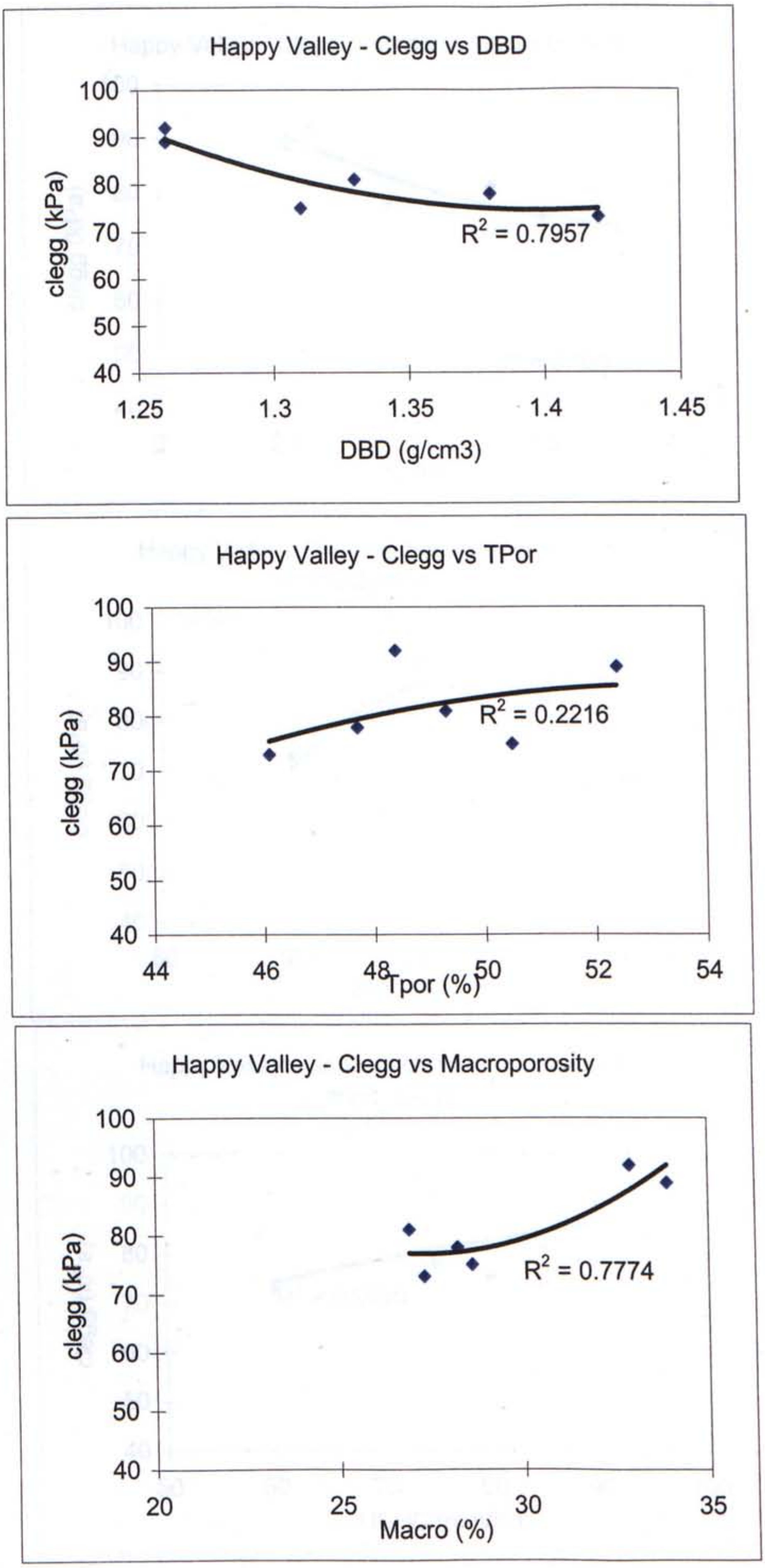
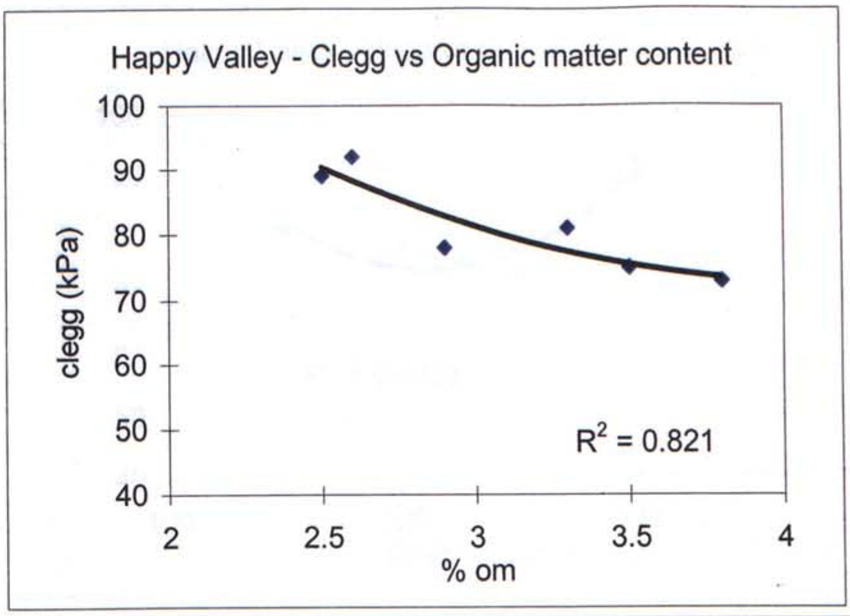
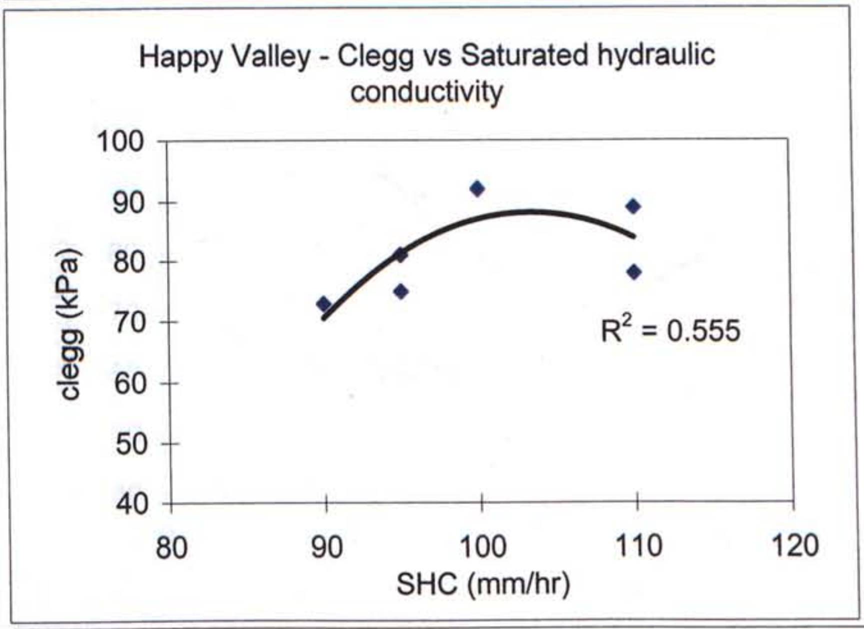


Figure 5.20 - Correlation of soil physical properties with clegg hammer values in Happy Valley





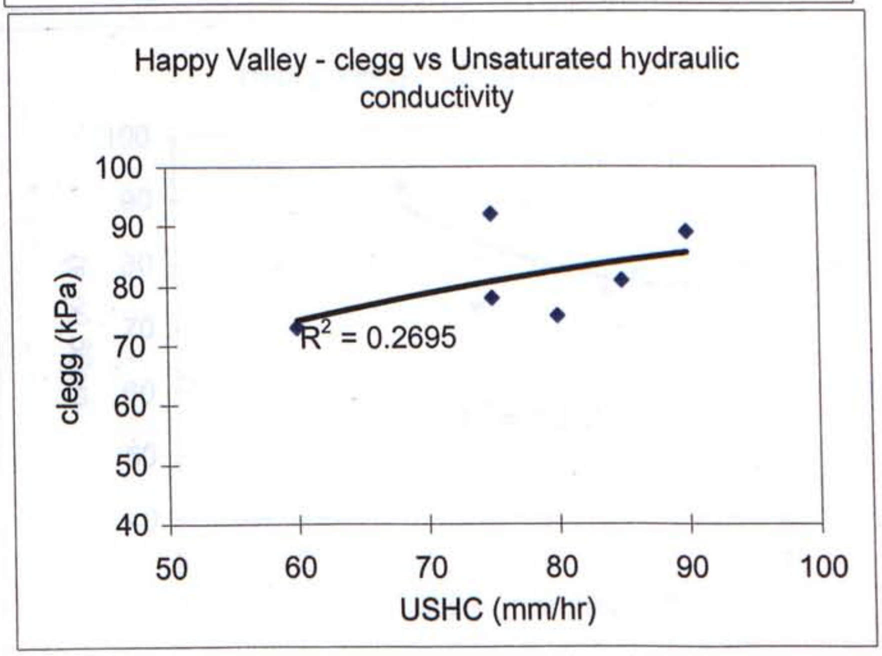
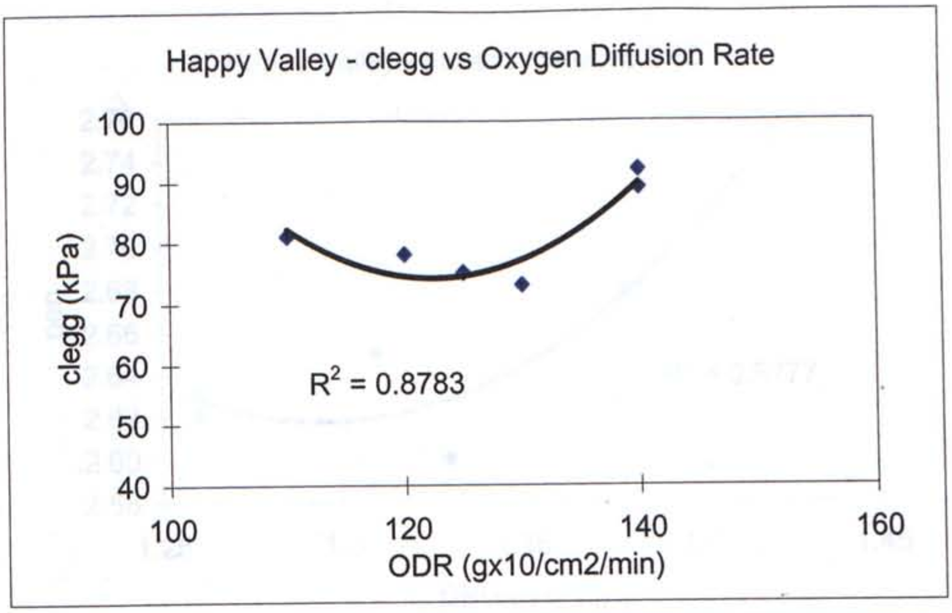
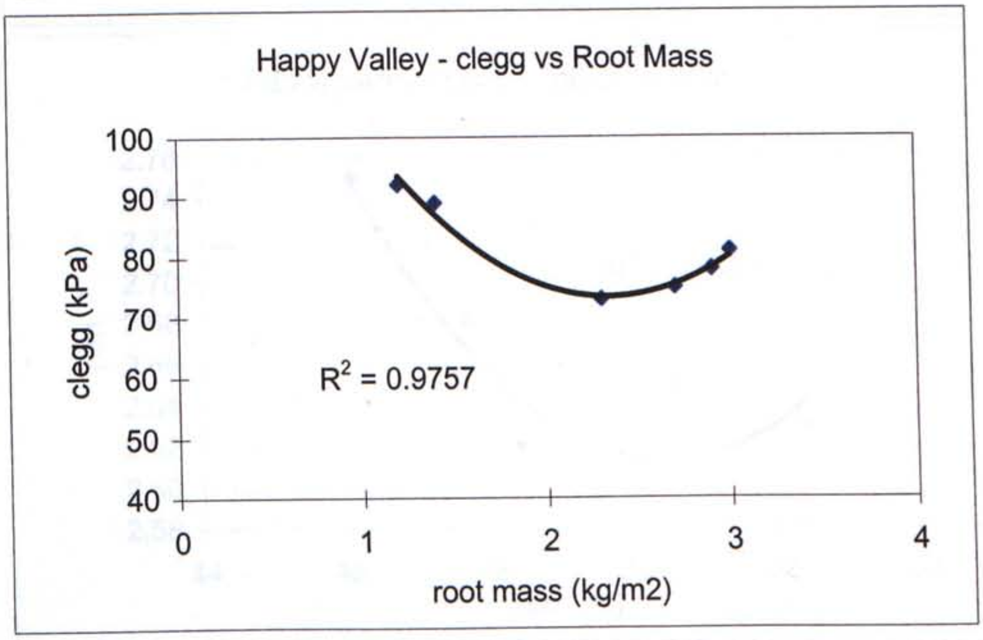


Figure 5.20 - Correlation of soil physical properties with clegg hammer values in Happy Valley





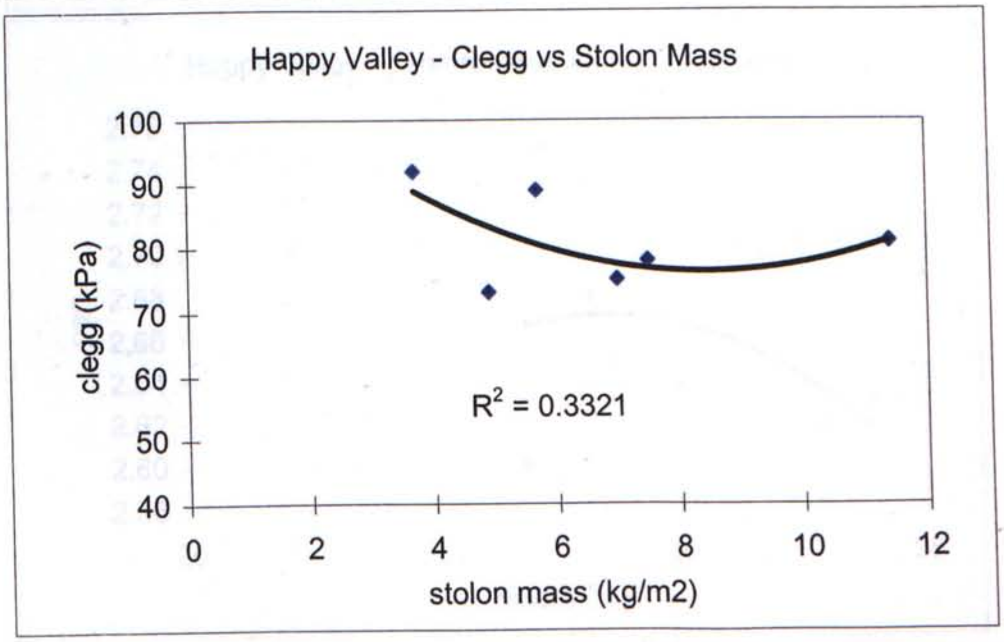


Figure 5.20 - Correlation of soil physical properties with clegg hammer values in Happy Valley

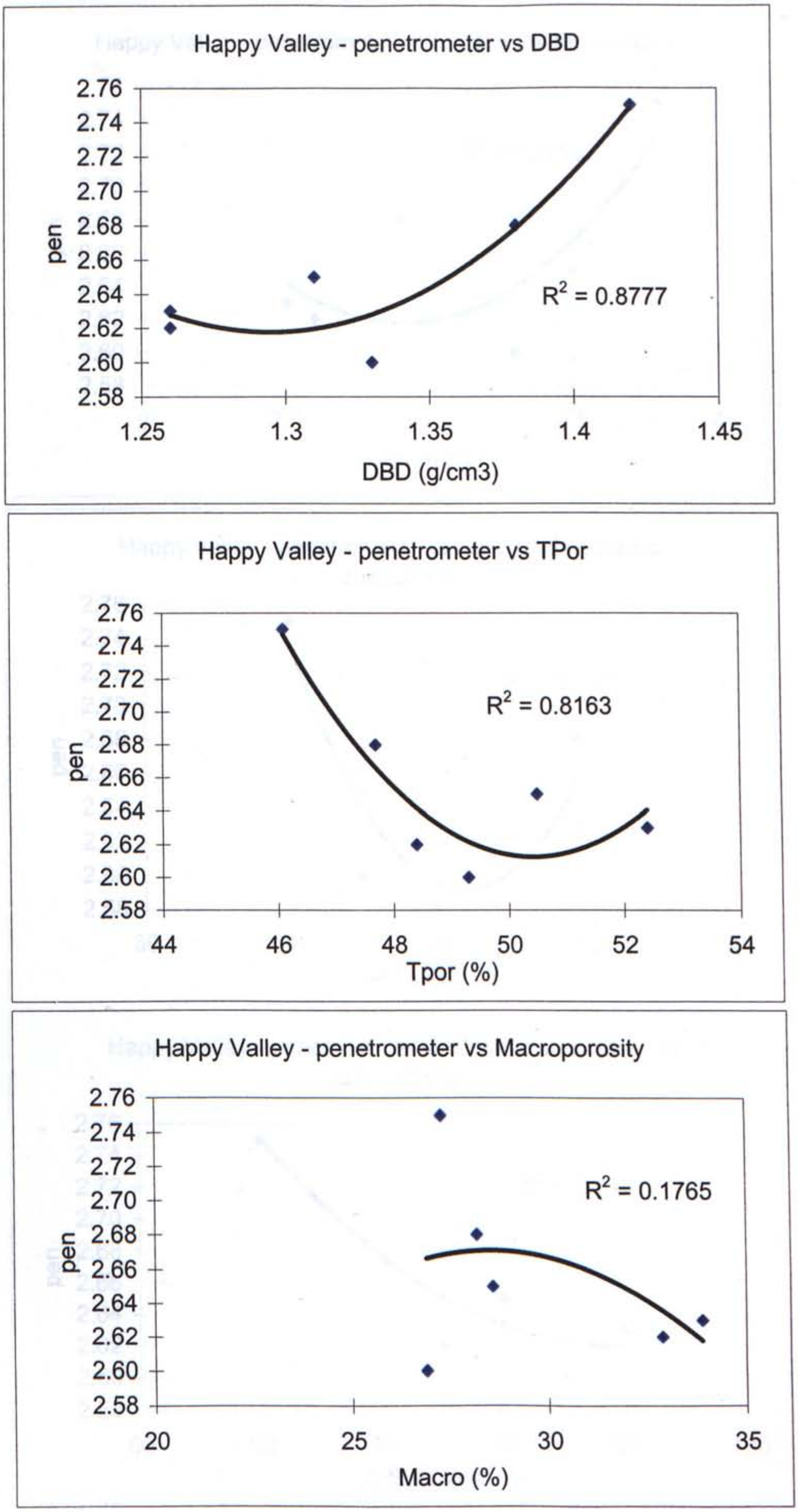
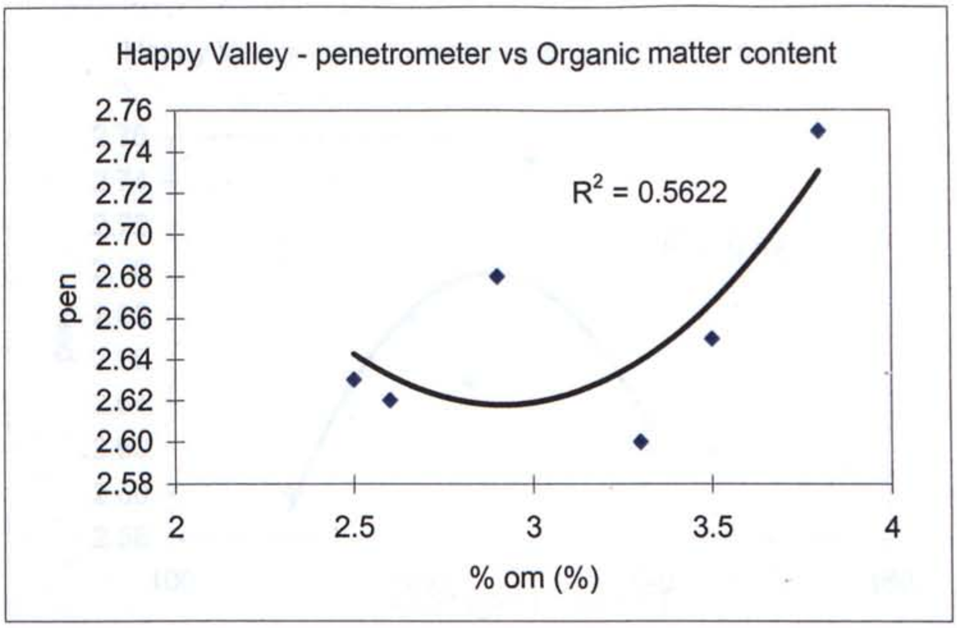
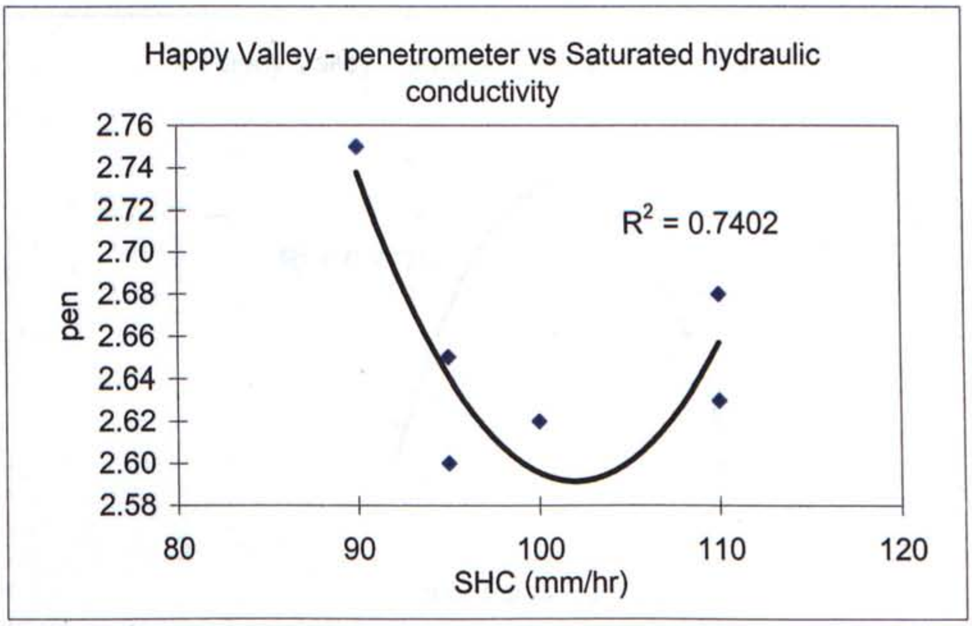


Figure 5.22 - Correlation of soil physical properties with penetrometer readings in Happy Valley





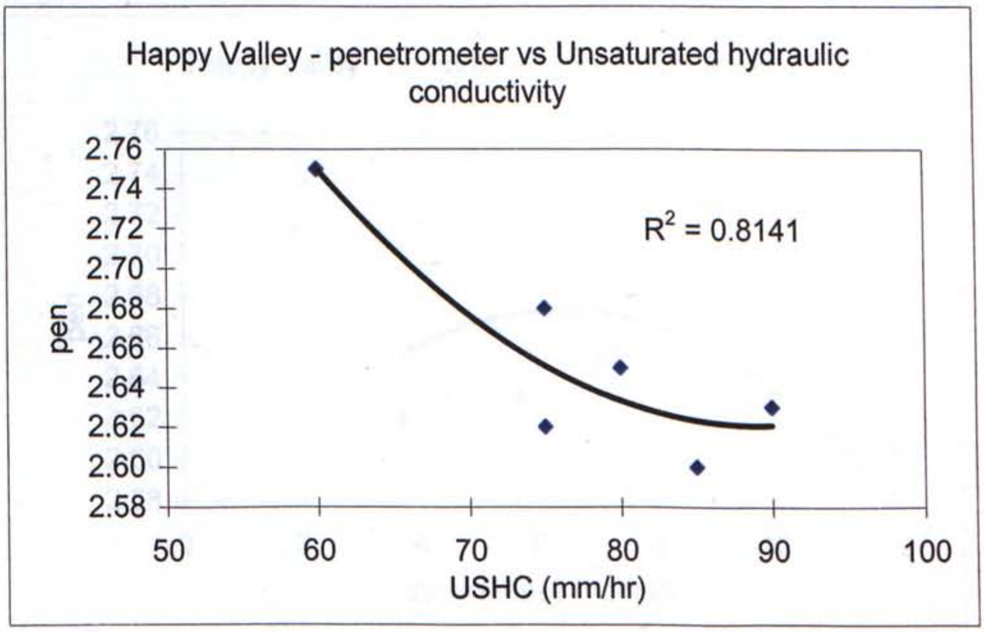


Figure 5.22 - Correlation of soil physical properties with penetrometer readings in Happy Valley

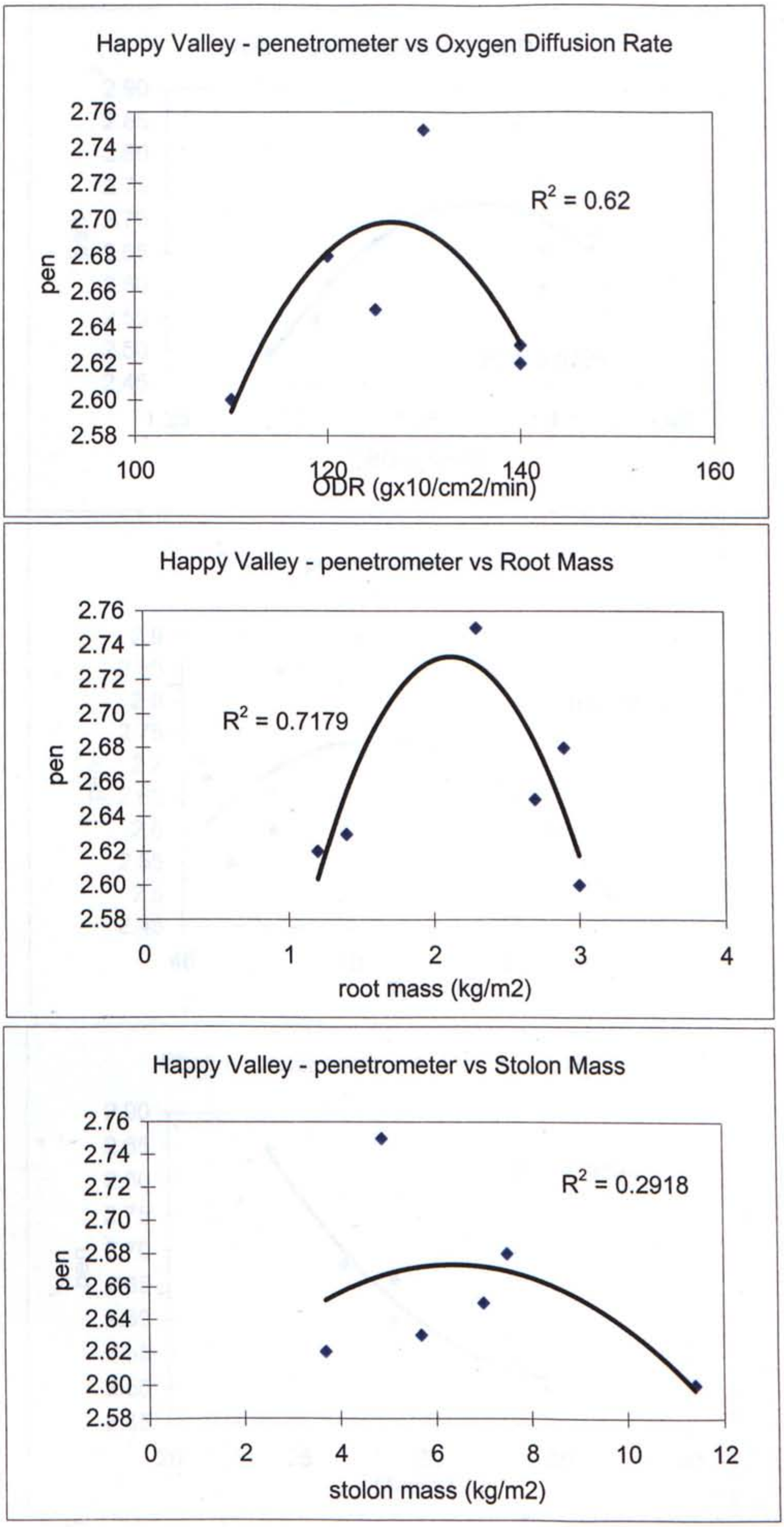


Figure 5.22 - Correlation of soil physical properties with penetrometer readings in Happy Valley

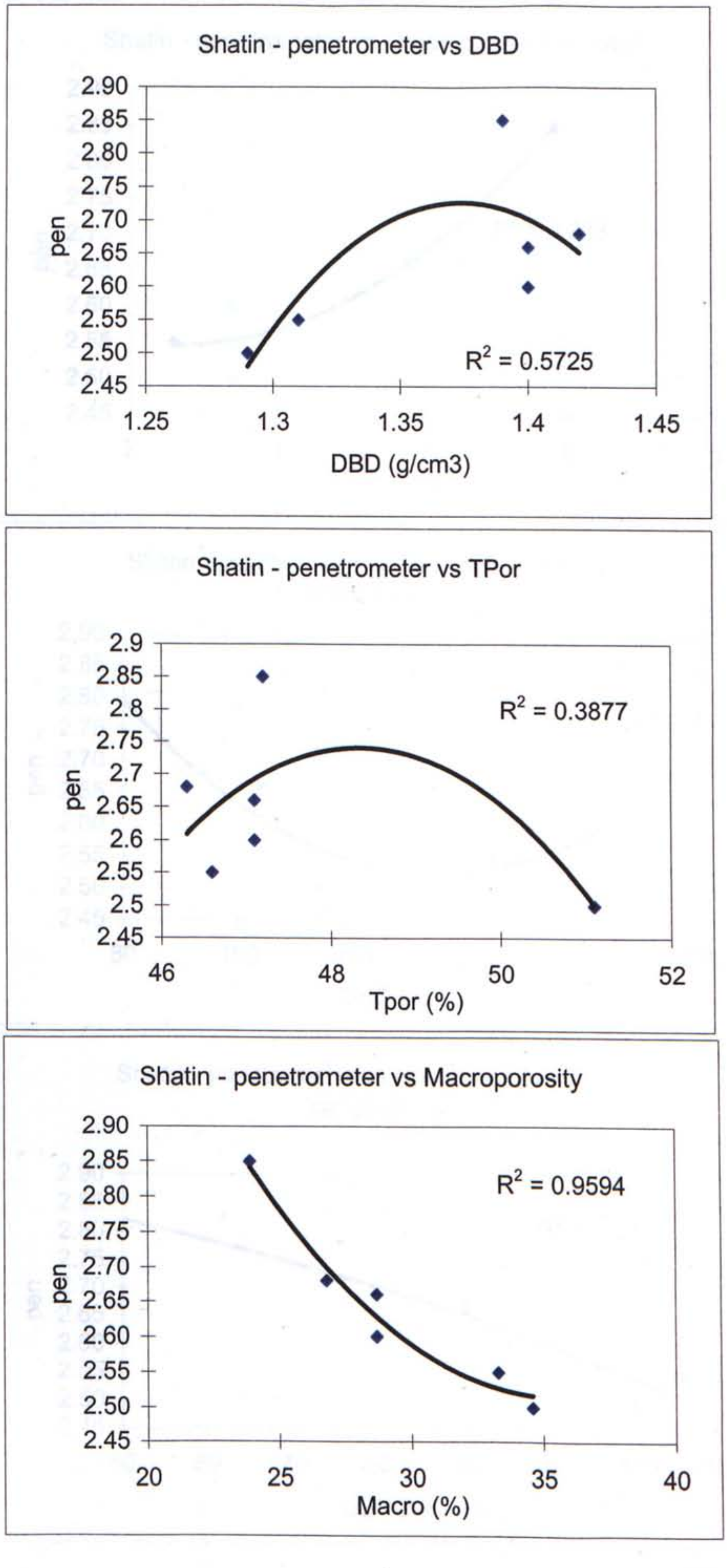


Figure 5.21 - Correlation of soil physical properties with penetrometer readings

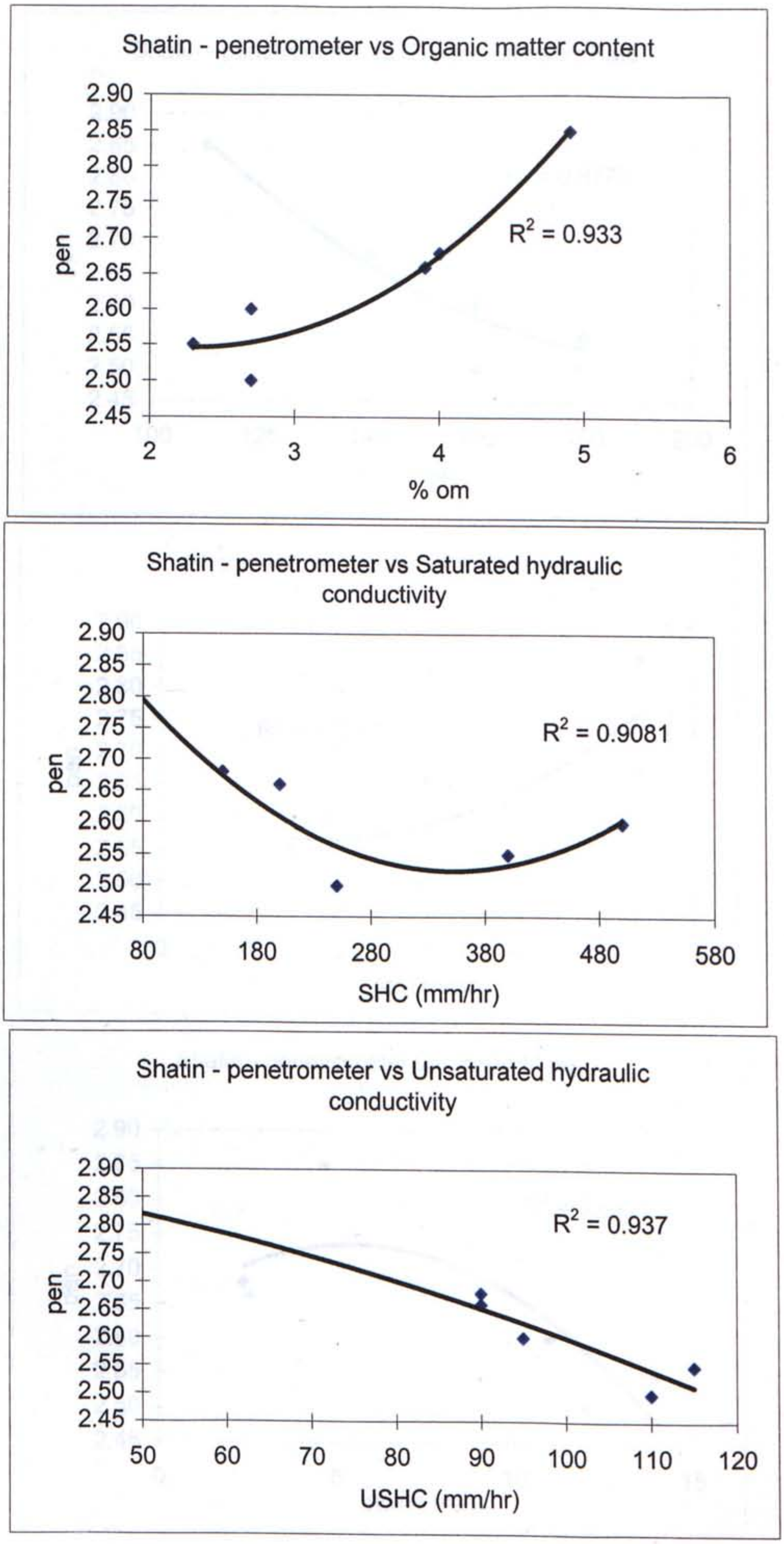


Figure 5.21 - Correlation of soil physical properties with penetrometer readings

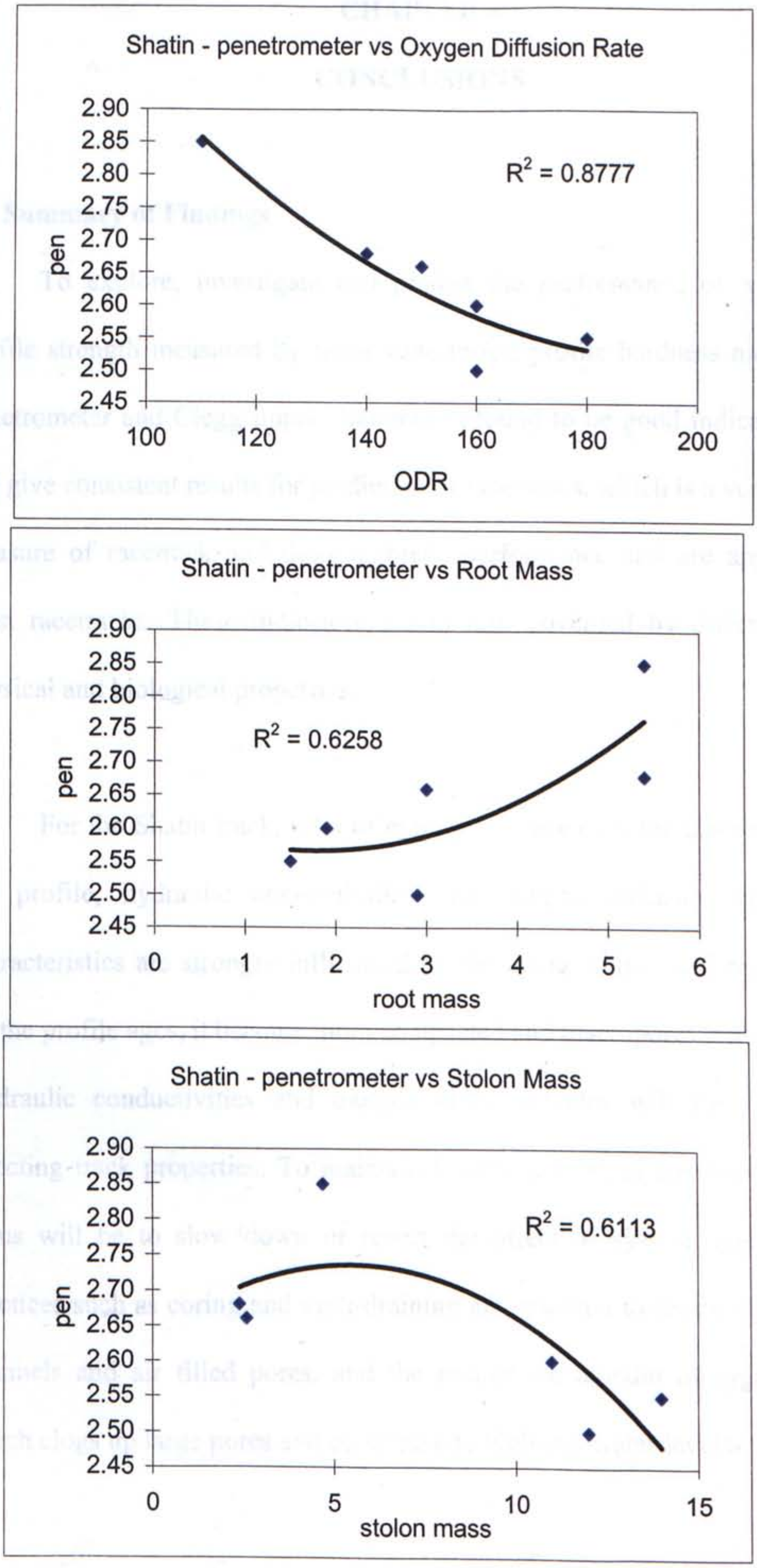


Figure 5.21 - Correlation of soil physical properties with penetrometer readings

CHAPTER 6

CONCLUSIONS

6.1 Summary of Findings

To explore, investigate and predict the performance of a racetrack, profile strength measured by shear vane tester; profile hardness measured by penetrometer and Clegg impact hammer is found to be good indicators. They can give consistent results for prediction of race times, which is a very common measure of racetrack and thoroughbreds performance and are applicable to most racetracks. These indicators are in turn governed by different profile physical and biological properties.

For the Shatin track, a lot of emphasis is place on the macroporosity of the profile, hydraulic conductivities and oxygen diffusion rates. These characteristics are strongly influenced by the aging of the sand mesh system. As the profile ages, it become more compacted and macropores start to collapse. Hydraulic conductivities and oxygen diffusion rates will then suffer and affecting track properties. To maintain Shatin at a prime condition, the main focus will be to slow down or revert the effect of system aging. Cultural practices such as coring and verti-draining are essential to create new drainage channels and air filled pores, and the reduce the amount of organic matter which clogs up large pores and contribute to high soil water levels.

Table 6.1 - Significant profile properties for performance index for Shatin Turf Track

	Shear strength	Clegg hammer reading	Penetrometer reading
Dry bulk density			
Total porosity			
Macroporosity	X	X	X
Organic matter content	X		X
Saturated hydraulic conductivty	X	X	X
Unsaturated hydraulic conductivity	X	X	X
Oxygen diffusion rate	X	X	X
Root mass	X		X
Stolon mass		X	

Table 6.2 - Significant profile properties for performance index for Happy Valley Turf Track:

	Shear strength	Clegg hammer reading	Penetrometer reading
Dry bulk density	X	X	X
Total porosity			X
Macroporosity	X	X	
Organic matter content	X	X	
Saturated hydraulic conductivty			X
Unsaturated hydraulic conductivity			X
Oxygen diffusion rate	X	X	
Root mass	X	X	X
Stolon mass			

The Happy Valley track was reconstructed in 1995; hence it is a much younger track. The track profile is still loose with insufficient organic matter to glue it together. For optimum performance, a lot of emphases are placed on increasing bulk density to desirable levels to provide adequate surface stability and strength; and increase root mass to hold sand particles together so as to reduce sandy kickbacks. The performance of the two new sections is inferior to the conventional old section, this is because the profile remains too dry and bulk density is too low. The area became unstable to race on and grass growth was ultimately negatively affected.When looking at soil physical properties alone, there is very little difference between the shaded and the full sun area. The most significant variance is in root and stolon mass. Tifton 419, which requires full sunlight for optimum growth will always be slower along the shaded front straight.

6.2 Implications of Study

6.2.1 Target Levels of Performance Indicators

As the measure of shear strength values, penetrometer readings and clegg hammer readings are very reliable and objective indicators of track performance, the Tracks management has setup target levels for these indicators to monitor performance and develop appropriate cultural practices programme when these indicators are out of the targeted range.

6.2.1.1 - Surface Strength Target Level

The target is for desired minimum levels of Shear Vane readings taken on random samples across the full width of the racing surface. The targeted minimum of Shear Vane value is 5.5 kPa. If value were less than the desired level, it would be necessary to investigate and identify the cause of the problem along the lines of:

- Moisture content – It is studied in terms of gravitational moisture content, macroporosity and hydraulic conductivities. If moisture content and water holding capacity is too low, pre-race irrigation is essential to preserve profile moisture. Alternatively, if water holding capacity is too high, that is the profile is too wet, more frequent coring and verti-draining could create larger pore space and drainage channels to reduce profile moisture.
- Turf grass root mass – As root system is essential to hold the sand/mesh profile together, stimulation of better grass growth would inevitably increase profile strength.
- Compaction level – This is measured in terms of dry bulk density and organic matter level. If profile were too loose and not sufficiently compacted, it would also be necessary to evaluate the benefit of rolling, which could increase surface strength instantly. However, frequent rolling would put extra stress on grass and increase profile compaction. The introduction of more organic matter in newly constructed profile could also help to glue sand particles together and hence the profile could be compacted easily to increase strength.

6.2.1.2 - Surface Hardness Target Level

The Clegg Hammer values and Penetrometer readings for the track, as prepared for racing, should fall between the values given below, using the standard drop height and weight.

Table 6.3 –Surface Hardness Target Level

Item	Minimum	Maximum
Clegg Hammer value (kPa)	70	100
Penetrometer reading	2.50	2.80

Clegg value higher than target and penetrometer reading lower than minimum would indicate that the track is too hard. It is then essential to start Verti-draining within a period not exceeding 4 weeks from the day of measurement. Verti-draining for new profiles would be scheduled with more discretion to ensure sufficient time for recovery before racing begins.

If Clegg value lower than target and penetrometer reading higher than maximum, the track is too soft. The necessity of rolling to increase surface hardness should be considered.

6.2.2 Turf management and cultural practice implications

6.2.2.1 Effect of aging and variations of profile age in Shatin

As the profile ages, changes and deteriorations of soil physical properties have been observed. To counteract these effects, a series of cultural practices have been prescribed throughout the year, renovation works during the season is limited due to the tight racing schedule, which often does not provide sufficient time for the track to recover from these profile renovation works.

The intensity of maintenance works are much higher during the off-seasons (Mid- June to end of August), two rounds of coring are scheduled to reduce the accumulation of organic matter and thatch. It is also very effective in creating new macropore space. Two rounds of verti-draining are scheduled to reduce surface hardness created by 9 months of horseracing and vehicle traffic. It could also create drainage and rooting channels as well as new macropore space.

As the Shatin racecourse consisted of sections of different ages, it is essential to balance the effect of ages through cultural practices. The older sections, such the Stable Bend area, will be cored three times to remove more organic material and to further increase drainage rates. In new areas, the corer and verti-drain will be worked at a shallower depth and with narrower tines in order to reduce the destructive effect of these maintenance practices and preserve surface stability and grass cover. During the racing season, these new areas might be omitted from renovation works if surface strength and recovery time is a concern.

Table 6.4 – Cultural Practices Schedule

Time	Cultural Practice	Function and purpose
October	Coring	Reduce Tifton density for overseeding
November	Verti-draining	Reduce surface hardness created by dry weather
March	Verti-draining	Create drainage channel and reduce surface hardness
	Verti-cutting	Reduce rye grass density and prepare for transition
May	Verti-draining	Create drainage channel and prepare for torrential weather
June	Coring	Reduce organic matter level and thatch accumulation
	Verti-cutting	Remove dead rye grass and reduce thatch accumulation
	Deep Verti-draining	Create drainage channel and introduce new macropore space; reduce surface hardness
July	Coring	Reduce organic matter level and thatch accumulation
	Deep Verti-draining	Create drainage channel and introduce new macropore space Reduce surface hardness

6.2.2.2 Effect of different profile design in Happy Valley

Owing to low bulk density and organic matter content, the StrathAyr new sections of Happy Valley are more delicate and prone to damage than the rest of the track. When planning for coring and verti-draining, extra care has to be taken to avoid further reduction in surface strength. To renovate these areas, it is more ideal to have a 3-week recovery period before the track is raced again to ensure that the grass cover will be dense enough and the profile to settle after cultural works. In addition, corer and verti-drain should operate at a shallower depth with narrow tines to avoid excess damage to grass service and creation of voids. These areas will also be rolled more frequently to consolidate the surface, increase bulk density and hence improve surface strength.

Apart from inferior surface strength and stability, the new sections of Happy Valley also drain faster than other sections of the track. To create an even surface for racing, these areas has to be watered heavier and closer to the start of first race to balance the effect of fast drainage. To increase water-holding capacity, attempts have been made to introduce finer sand into the profile to increase profile moisture content. However, topdressing during racing season has to be very thin and used with high discretion, therefore the process of profile improvement is very slow and distinctive effects are yet to be observed.

6.2.2.3 Effect of shading in Happy Valley

Little differences have been observed in the soil physical properties between the full-sun and shaded area of the track. Water retention is higher in shaded area due to lower evapotranspiration rates; to produce a consistent track for racing less water is being applied onto these sections especially on racedays to balance the effect of shade.

Root and stolon mass is lower in the shaded section; truss with artificial greenhouse lights have been used to compensate for lower sunlight hours. However, the size of the light truss (2m x 4m) is incomparable to the area of the track (total area of 5.4 hectare and shaded area of 1.2 hectare) and cannot cover the entire shaded area. In addition, the light intensity of greenhouse lights is incomparable to that of full sunlight. Therefore, the effect of artificial lighting is insignificant. Very little can be done to make up for the effect of shading, and growth rates of the shaded home straight area will always be slower than other sections.

6.2.3 Construction material and design

In the past, the depth of sand profile was determined by engineers without consideration of the particle size distribution and water release characteristics of the sand. Sand profiles of the old sections is in general too deep creating a drier track whereas the Happy Valley new sections are too shallow creating a profile that is wet at the bottom and dry at the surface. To construct a profile with appropriate depth of sand, the depth of profile must be determined through the moisture release characteristic of the construction sand. The ideal depth should be equivalent to the tension at which 50% of the total pore space is filled with water.

In addition, the current particle size distribution of the racetrack sand is determined based on studies and standards developed for golf greens and sports fields but not specifically for horseracing. Previous Tracks Consultants has commented the sand as too coarse to provide appropriate stability for racing. Future constructions should focus on sourcing a sand that could provide enough drainage to cope with the torrential rainfall of Hong Kong yet fine enough to provide sufficient surface stability.

6.2.4 Managing user intensity

Although the number of race meetings in the past three seasons remains to be 78, the number of races per raceday has increased so has the total number of horses raced on the tracks. This translates to increasing use intensity and the possibility of further increasing the total number of racedays. The length of the racing season has extended in the past 2 year (2000-2003) and the timeframe for off-season renovation is progressively narrow.

As the pressure to increase the number of races in order to increase betting turnover and to cope the expanding horse population is inevitable. It is therefore necessary to conduct more renovations during the racing season to maintain the turf tracks at their prime conditions. Race meetings have to be spaced strategically to leave room for seasonally renovations such as overseeding in October, verti-draining in November to relief hardness, transition works in March and April and preparation works for torrential weather in May. Without proper breaks in the racing fixture for both courses and scheduling Dirt races in critical times, the turf tracks would be unable to handle additional races and the standard of racing could be jeopardized.

6.3 Limitations of Study

In this study, most of the data on profile physical properties were collected in the laboratory rather than *in situ*. The collection of field data might be able to better reflect real life performance. However, the collection of field data needs to corporate with the racing and the busy day-to-day track maintenance programme.

This study focuses on the comparison of areas of different age group to diagnose the effect of aging. It is also possible to monitor particular sections of the track over a longer time span to explore the process of aging in each section.

6.4 Further Studies

6.4.1 Shear Strength Tester

Shear strength is an important indicator of track performance and gives a good prediction of race times. The current shear vane used in the racecourse has a vane size of 20mm wide and 50mm deep, which is very small when compared with a horse's hoof. New shear vanes of larger sizes have been developed and would better represent the action of a horse's hoof during gallops. However, a larger vane with bigger plates would meant that the instrument would be larger and heavier, which makes it more difficult to be used on the track and would be more destructive when sampling.

Further collection of data from new shear vane on race days and on monthly basis would help to evaluate the representation of new shear vane readings and profile strength. It would also be necessary to correlate these new readings with race times and with results from old shear vane to study whether these larger vanes would be better than the old vane.

6.4.2 Maximum Life of Sand Mesh Profile

The Shatin Stable Bend area was constructed in 1989 without any major renovation since then. Although this area has received additional coring to reduce the organic matter level and to improve drainage rates, it remains to be very high in organics and very wet most of the time. The condition of grass surface has begin to deteriorate especially during the transition period when the dying rye grass got glued down onto track surface, hence suffocating the immersing bermuda grass.

Most of the studies and recommended ranges of soil physical properties were conducted on pure sand golf greens and sports fields and studies of racetracks were mostly done on soil based or sand/soil tracks. Recommended levels suggested by these studies has little application to sand mesh tracks because before a sand mesh has reached these pre-set limits, it would have failed to be raced on properly. It is therefore necessary to determine the maximum lifetime of a sand mesh and determine the usable life before total reconstruction is needed.

6.4.3 Problems with Newly Constructed Profile

After the re-development of Happy Valley turf track in 1995, a lot of problems were discovered concerning surface dryness, lack of surface strength and stability and high leaching rates of nutrients. In some of the areas reconstructed after 1995, the top layer of sand was mixed with organic matter from the old profile to generate a layer of diluted organic-enriched sand to avoid the new-profile syndrome. Sections reconstructed by this method seemed to perform well without problems of dryness and instability but it is necessary to study whether the premature aging of these sections will occur and the rate of aging compared with areas build or reconstructed by conventional method. It would very interesting to compare the physical properties of these areas with others to determine the actual 'age' the profile behaves as. If the organic enriched profile behaves similarly to other profiles of the same age, then this kind of reconstruction method could be widely adopted to avoid the new-profile syndrome and could save a lot of time in waiting for the track to mature to it optimal performance.

REFERENCES

Baker, S.W. (1990) Sands for Sports Turf Construction and Maintenance. The Sports Turf Research Institute, Bingley, U.K.

Baker, S.W. (1995) "The Effect of Rootzone Composition and Grass Type on the Performance of Turf for Horse Racing in Malaysia." Journal Sports Turf Research Institute Vol. 7: p 42-51.

Ball, B.C., O'Sullivan, M.F. and Hunter, R. (1988) "Gas Diffusion, Fluid Flow and Derived Pore Continuity Indices in Relation to Vehicle Traffic and Tillage." Journal of Soil Science Vol. 39: p 327-339

Beard, J.B. (1973) Turfgrass: Science and Culture. Prentice Hall, Inc. New Jersey.

Beard, J.B. and Sifers, S.I. (1989) "A Randomly Oriented, Interlocking Mesh Element Matrices System for Sports Turf Root Zone Construction." Proceedings of the 6th International Turfgrass Research Conference, Tokyo. p 253-257.

Beard, J.B. and Sifers, S.I. (1993) "Stabilization and Enhancement of Sand-modified Root Zones for High Traffic Sports Turfs with Mesh Elements." Texas Agricultural Experiment Station and Department of Soil and Crop Sciences.

Bengeyfield, W.H. (1975) USGA Green Section Record, United States Golf Association.

Bingaman, D.E. and Kohnke, H. (1970) "Evaluating Sands for Athletic Turf." Agronomy Journal Vol. 2: p 464-467.

Bunt, A.C. (1991) "The Relationship of Oxygen Diffusion Rate to the Air-filled Porosity of Potting Substrates." Acta Horticultural 294: p 215-224.

Canaway, P.M. (1993) "Effects of Using Seed, Sod and Juvenile Sod for the Establishment of an All-sand Golf Green Turf and on its Initial Performance Under Wear." International Turfgrass Society Journal 7: p 469-475.

Canaway, P.M. and Baker, S.W. (1993) "Soil and Turfgrass Properties Governing Playing Quality." International Turfgrass Society Research Journal 7: p 192-200.

Carrow, R.N. and Wiecko, G. (1989) "Soil Compaction and Wear Stresses on Turfgrasses: Future Research Directions." The 6th International Turfgrass Research Conference: p 37-42.

Carter, M.R. (1990) "Relative Measures of Soil Bulk Density to Characterize Compaction in Tillage Studies on Fine Sandy Loams." Canadian Journal of Soil Science Vol. 70: p 425-433.

Carter, M.R. and Steed, G.R. (1992) "The Effects of Direct-drilling and Stubble Retention on Hydraulic Properties at the Surface of Duplex Soils in North-Eastern Victoria." Australia Journal of Soil Research Vol. 30: p 505-516

Catrice, H. (1993) "Turf for Horse Racing: Conflicting Requirements of the Turf Grass Plant and the Racing Horse." International Turfgrass Society Research Journal 7: p 517-521.

Clothier, B.E. and White, I. (1981) "Measurement of Sorptivity and Soil Water Diffusivity in the Field." Journal of Soil Science Society America Vol. 45: p 345-395.

Davis, W.B. (1980) "Sands and Your Putting Green" California Turfgrass Culture

Davis, W.B. (1983) "Examples of Real Solutions – The Fine Sand Green" California Turfgrass Culture

Davis, W.B., Farnham, D.S. and Gowans, K.D. (1990) "The Sand Football Field" California Turfgrass Culture Vol. 24, No. 3: p 17-22

Dirksen, C. (1985) "Determination of Soil Water Diffusivity by Sorptivity Measurements." Journal of Soil Science Society America Vol. 39: p 22-27.

Field, T.R.O. and Murphy, J.W. (1990) "Some Soil Physical Characteristics of Melbourne Racetracks." Unpublished Report from Turf Research Section, Grassland Division, D.S.I.R., Palmerston North.

Field, T.R.O., Murphy, J.W. and Hamlin, A.J. (1986) "Racetrack Research Programme. New Zealand Racetrack Survey. Report on Te Rapa, Avondale and 10 Central Districts." Unpublished Report from New Zealand Racing Authority.

Field, T.R.O., Murphy, J.W. and Hickey, M.J. (1993) "Age Development in Sand-based Turf." International Turfgrass Society Research Journal 7: p 464-468.

Field, T.R.O., Murphy, J.W. and Lovejoy, P.I. (1993) "Penetrometric Assessment of the Playability of Coarse Turf." Proceedings of the 7th International Turfgrass Research Conference, Florida. p 512-516.

Gibbs, R.J., Adams, W.A. and Baker, S.W. (1989) "Factors Affecting the Surface Stability of a Sand Rootzone." Proceedings of the 6th International Turfgrass Research Conference, Tokyo. p 189-191.

Hakansson, I. (1990) "A Method for Characterizing the State of Compactness of the Plough Layer." Soil and Tillage Research Vol. 16: p 105-120.

Latham, J.M. (1999) "Putting Green Construction: Interpreting Physical Soil Test Data." USGA Green Section Record: p 4-7

Marshall, T.J., Holmes, J.W. and Rose, C.W. (1996) Soil Physics 3rd Ed. Cambridge, University Press.

McCoy, E.L. (1992) "Quantitative Physical Assessment of Organic Materials Used in Sports Turf Rootzone Mixes." Agronomy Journal 84: p 375-381.

McIntyre, K and Jakobsen, B. (1993) "Design, Construction and Maintenance of Sand Based facilities Using the Principle of the Perched Water Table." Turf Craft Australia. May 1993: p 47-53.

Meek, B.D., DeTar, W.R., Rechel, E.R. and Carter, L.M. (1990) "Infiltration Rate as Affected by an Alfalfa and No-till Cotton Cropping System." Journal of Soil Science Society America Vol. 54: p 505-508.

Murphy, J.W. (1997) "The Awapuni Tracks Rating report" AgResearch Reports

Murphy, J.W. and Field, T.R.O. (1996) "An Index of Compaction for Soils under Turf Surfaces." AgResearch Reports

Murphy, J.W. and Nelson, S.H. (1979) "Effects of Turf on Percolation and Water Holding Capacity of Three Sand Mixtures." New Zealand Journal of Experimental Agriculture 7: p 245-248.

Murphy, J.W. and Nelson, S.H. (1979) "Physical Characteristics of Particle Size and Distribution on Penncross Bentgrass." New Zealand Journal of Experimental Agriculture 7: p 249-255.

Murphy, J.W. and Nelson, S.H. (1979) "Preliminary Investigations of Sand Growth Media for Cotula." New Zealand Journal of Experimental Agriculture 7: p 257-261.

Nelson, S.H. (1979) "Towards Improved Sports Fields" Excerpts from talk at Alberta Turfgrass School

Nelson, S.H. and Murphy, J.W. "Sand Culture for Sports Turf in New Zealand." Unpublished paper from Turf Research Section, Grassland Division, D.S.I.R., Palmerston North.

Perroux, K.M. and White, I. (1988) "Designs of Discs Permeameters." Soil Science America Journal 52: p 1205-1215.

Pierrang, M. and Catrice, H. (1989) "Turf for Horse Racing: Thatch Maintenance." Proceedings of the 6th International Turfgrass Research Conference, Tokyo. p 247-248.

Radko, A.M. "The Sand Syndrome – Its Fallacies, Facts and Future"

Radko, A.M. (1974) "Refining Green Section Specifications for Putting Green Construction." Proceedings of the 2nd International Turfgrass Research Conference p 287-297.

Schmidt, R.E. and Henry, M.L. (1989) "*Cynodon dactylon* (L) Pers. Postdormancy Growth as Influenced by Overseeding *Lolilum perenne* L. and using growth regulators." The 6th International Turfgrass Research Conference: p 161-163.

Skirde, W. (1989) "Problems and Research on Sports Turf Areas in West Germany, with Particular Reference to the Deterioration in Environmental Conditions." The 6th International Turfgrass Research Conference.

Smiths, K.A. and Mullins, C.E. (1991) Soil Analysis: Physical Methods. Marcel Dekker, New York.

Soane, B.D. (1990) "The Role of Organic Matter in Soil Compactibility: A Review of some Practical Aspects." Soil and Tillage Research 16: p 179-201.

Stolte, J., Freijer, J.I., Bouten, W., Dirksen, C., Halbertsma, J.M., Van Dam, J.C., Van den Berg, J.A., Veerman, G.J. and Wosten, J.H.M. (1994) "Comparison of Six Methods to Determine Unsaturated Soil Hydraulic Conductivity." Journal of Soil Science Society America Vol. 58: p 1596-1603.

Stolzy, L.H. and Letey, J. (1964) "Characterizing Soil Oxygen Conditions with Platinum Microelectrode." Soil Science America Journal 28: p 249-279.

Taylor, D.H. and Blake G.R. (1979) "Sand Content of Sand-Soil-Peat Mixtures for Turfgrass" Soil Science Society America Journal, Vol. 43: p 394-398.

Taylor, D.H., Williams, C.F. and Nelson, S.D. (1991) "Measuring Water Infiltration Rates of Sports Turf Areas." Agronomy Journal 83: p 427-429.

Thomas, V.J., Murphy, J.W. and Field, T.R.O. (1996) "Racetrack Traction Assessment by Penetrometer. Part I The Model." Journal of Turfgrass Management Volume 14: p 37-49.

Thomas, V.J., Murphy, J.W. and Field, T.R.O. (1996) "Racetrack Traction Assessment by Penetrometer. Part II The Application of the Model." Journal of Turfgrass Management Volume 14: p 51-61.

White, I. and Sully, M.J. (1987) "Macroscopic and Microscopic Capillary Length and Time Scales from Field Infiltration." Water Resources Research, Vol. 23 No. 8: p 1514-1522